VISCOSITY AS A MEASURE OF QUALITY IN WHEAT VARIETIES

by

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INTRODUCTION

Flour is one of the most common food substances used in preparing the diet of the average individual as well as one of the most extensively commercialized economic products. Large differences exist between flours milled from different wheat varieties with reference to their quality and value as bread flours. As a result it is most desirable that there be a satisfactory method of differentiating between the many types of flours produced from different wheats.

New varieties of wheat are constantly coming on the market and are thus available in commercial quantities to the miller. Occasionally these new varieties become widespread on account of their excellent agronomic characteristics and because they are not subjected to adequate chemical and physical methods for determining the quality of flour milled from them. Later they prove to be unsuitable as bread flours for which they are being used. Such wheats, once established, cause considerable loss to the milling industry as well as much grief for the baker, with the result that an inferior loaf of bread is produced. Removal of these wheats desirable from an agronomic point of view but undesirable from a bread making standpoint requires years

of effort and propaganda. A satisfactory method for determining the quality of bread flours would be valuable in eliminating such varieties while in the hands of the plant breeder as well as aiding the chemist in selecting bread flours that are superior in quality.

The study of viscosity has been undertaken with the purpose of determining its value in differentiating between desirable and undesirable bread flours when applied to a characteristic titration procedure which gives specific differences for flours possessing different physico-chemical properties.

REVIEW OF LITERATURE

In the following discussion no attempt has been made to review the more important chemical and physico-chemical factors such as crude gluten, total protein, gliadin-glutenin ratio, gliadin content, glutenin content, water soluble proteins, fat content, phosphorus content, mechanical strength testers, enzymes of wheat flour, gas production and gas retention capacity, and hydrogen-ion concentration. These factors have been investigated extensively by various workers in an attempt to throw light on their relation to flour quality.

The discussion, on the other hand, has been limited to colloid-chemical investigations, principally viscosity, with

relation to flour. A large amount of work has been done in the past 30 years by workers who have carried out colloid-chemical investigations of the strength of wheat flours in an effort to determine the colloidal factors that might influence the baking value of different flours. An excellent review of this work up to 1923, and including the outstanding investigation of Lüers and Ostwald (1919), has been given by Sharp and Gortner (1923) who carried out the second outstanding investigation on viscosity as a physical property of flour.

The author, therefore, has reviewed only the more important investigations on viscosity and flour from 1923 to the present time.

Sharp and Gortner (1923) studied viscosity as a measure of the hydration capacity of wheat flour and its relation to baking strength. They used a series of wheat flours of various grades and baking strength in an effort to investigate the relation of the colloidal properties of wheat proteins to the strength of flour. The method adopted in their investigation for the study of the imbibitional power of the proteins in wheat flour was to measure the viscosity of flour-in-water suspensions, and the changes in viscosity produced by various treatments, using a MacMichael viscosimeter.

Sharp and Gortner (1923), in the first phase of their work, studied viscosity of original flour-in-water suspensions as affected by various amounts of different acids. In this investigation the viscosity as affected by a series of normal acids was studied to see if the various acids behaved alike with the different flours. They found that maximum viscosity produced by the various acids acting on wheat flours occurs at approximately the same hydrogen-ion concentration regardless of the acid. The hydrogen-ion concentration for maximum viscosity was found to be slightly higher than a pH of 3. The highest viscosity produced by the different acids occurs at practically the same hydrogen-ion concentration with the different flours. This work was evidence that different acids apparently do not produce the same maximum imbibitional effect with wheat proteins. The fact that certain acids produced imbibition with one flour and practically no imbitition with another while metaphosphoric acid produced no imbibition with either flour was undoubtedly connected with the behavior of these acids as protein precipitants.

Sharp and Gortner, in a study of the effect of added salts on imbibition produced by lactic acid, made the water which the flour was treated .01 normal with respect to several salts and the effect of lactic acid on imbibition

was measured by the viscosity method. It was found that salts divided themselves into sharply defined groups in respect to their ability to inhibit imbibition produced by lactic acid. These groups were found to be the same with the two flours investigated and were not determined by the valency of the ions.

They next investigated the effect of electrolytes present in the original flour on viscosity. As a result of conductivity measurements, Bailey and Collatz (1921) showed that the soluble electrolyte content of a water extract of wheat flour was related to the ash content of the flour; hence the viscosity of a low grade flour should be depressed more than that of a high grade flour, because of the difference in soluble electrolytes contributed to the extract by the flour itself. Thus the true imbibitional strength of the proteins present would be somewhat masked by the ash content. Flours of different grades contributing different amounts of salts should not be expected to respond alike.

In order to investigate this point, they chose two flours of widely different ash content. It was found that extracting 18 grams of the flour with one liter of water, centrifuging, discarding the supernatant liquid, and then making the residue up to a total volume of 100 c.c., increased the viscosity of a flour with a high ash content

from 75 to 329 degrees MacMichael. A flour with a relatively lower ash content increased from 392 to 502 degrees. This confirmed their supposition that the difference in soluble salts of the different flours was changing the order of their relative viscosities. A second extraction with one liter of water was not found to appreciably affect the viscosity. This treatment with one liter of water was found to reduce the salt content as shown by conductivity determinations, to at least one-fifteenth its original value. A subsequent extraction with one liter of water was found to reduce the content only slightly further.

As a result of the demonstrated effect of the soluble salts, Sharp and Gortner, after extracting with one liter of water, repeated the viscosity determinations with the various acids on the same flours that were previously treated with different acids. Here they found that the materials extracted from flour by water influence the imbibitional power of the various acids in different degrees. The water extract from various flours differs in its effect on imbibition produced by different acids. They also found that the freshly prepared meta-phosphoric acid produced imbibition. This indicated its efficiency as a protein precipitant. The series of acids arranged in the order of their ability to produce maximum viscosity is more

nearly the same for the different flours after the removal of the soluble extract.

They next studied the effect of sodium and barium hydroxide on the viscosity of flour suspensions. It was found that barium hydroxide had relatively less effect on the viscosity of the flour suspensions than sodium hydroxide. Also viscosity in the presence of alkalies was not so markedly affected by the soluble materials present in the natural flour as in the presence of acids. The maximum viscosity produced by alkalies occurred at approximately a pH of 11.

Sharp and Gortner investigated the effect of concentration on viscosity to see whether or not the order of the relative viscosities of the various flours would remain the same if the viscosity effects were measured at different concentrations. They found that concentration did affect the results. Maximum viscosity and concentration of flour were found to conform to the logarithmic expression,

Log of viscosity = a + b (log of concentration)

in which the "log of viscosity" is the logarithm of the maximum viscosity obtained with lactic acid, "a" is the logarithm of the viscosity reading when log of concentration is zero, and "b" is the tangent of the angle made by the logarithmic curve with the axis of abscissa. The values of

these constants as well as methods of calculation were given. They concluded that apparently the value of the constant "b" expressed more nearly the imbibitional strength of the various flours. The values for the constant "a" were found to vary markedly when the concentration was calculated on the basis of grams of flour per 100 cc. If the concentration of the protein content was used the values for "a" more nearly approached each other, while if the concentration was expressed as glutenin the values for "a" showed still greater agreement.

Gliadin is reputed to have but a slight solubility in distilled water. Sharp and Gortner, however, found that repeated extractions of flour with distilled water removed practically all the alcohol-soluble proteins, the first extraction removing proportionately more than the subsequent extractions. They found that glutenin was the protein mainly responsible for the marked imbibitional power of flour and gluten as influenced by acids and alkalies. The treatment of glutenin of flour with alcohol of a concentration of 70 per cent or more markedly affected the colloidal properties of the glutenin as measured by viscosity. Their results indicated that the glutenin content and its imbibitional properties should be taken into account in investigations of flour strength.

Sharp and Gortner found, when considering the relation of viscosity, glutenin content, and loaf volume, that doughs which had been brought to a pH of 3.0 or 11.0 by the addition of acid or alkali, after which the acid or alkali was neutralized, had lost their baking strength. Flours that contained a protein which responded markedly to the increasing imbibitional effect of lactic acid lost their baking strength after they were doughed up with 70 per cent or 90 per cent alcohol and then dried. It was stated, however, that the baking strength of flour was lost by extraction of the flour with alcohol but that this was not proof that the gliadin was the protein mainly concerned with flour strength.

As a result of the preceding work of Sharp and Gortner as well as that of Gortner and Doherty (1918), it was concluded that there was an inherent difference in the physicochemical properties of the gluten from strong and weak flours and that these differences were due to the colloidal state of the gluten proteins. In addition it was shown that the differences in colloidal properties apparently resided in the protein glutenin.

Gortner (1924) pointed out that absolute viscosities of flour-water suspensions may yield results which may be wrongly interpreted because the viscosity is the resultant of two factors, the "quantity" and "quality" of the glutenin present in the flours. A method, however, was described for

determining a constant which was apparently characteristic of the quality of the glutenin present in wheat flour.

Smith (1925) using a Sheely pipette viscosimeter and working with ten flours of different types and grades found that all the flours having a high viscosity were of excellent baking quality. The flours of low viscosity were found to range from excellent to poor in baking quality.

Johnson, Herrington, and Scott (1929), and Collatz (1922) have suggested the possibility of using the viscometric method for studying proteolysis in fermenting bread doughs. In their studies flour-water suspensions which were subjected to extended autolysis were used. With such a procedure, the viscometric method revealed changes taking place in the flour proteins.

The fact that such changes in the gluten proteins are taking place and still no parallel chemical changes can be detected tends to amplify the degree to which colloid chemistry comes into play in the making of bread.

Sasse and Pearson (1930), after running several thousands of tests on many different brands and grades of flour with the MacMichael viscosimeter, concluded that the viscosity test added nothing to the information obtained from the protein and ash determinations and can never be made to replace the baking test.

Bayfield (1932) designed a viscosimetric method using suitably ground whole wheat meal for the purpose, primarily, of eliminating poor milling varieties while in the hands of the wheat breeder. The procedure which used a MacMichael viscosimeter was relatively simple and required a comparatively short time for testing a sample. It was found that wheat varieties of poor milling quality gave much larger viscosity readings than varieties which milled readily and gave low ash flours. Statistical studies indicated that this test was positively correlated with the protein content of the whole wheat and also with the ash content of experimentally milled flours obtained from this wheat.

The Kunitz formula for converting the relative viscosity of lyophilic solutions into a value expressing the volume occupied by the disperse phase was applied by Gortner (1933) to the viscosity data of starch solutions. The following conclusions were evident:

(1) Starches derived from various botanical sources differ widely in hydration capacity.

(2) Wheat starches from different wheat varieties differ somewhat in hydration capacity, but not nearly so much as the values for the relative viscosity of the respective solutions would indicate.

(3) The hydration capacity of wheat starch (volume occupied by one gram of the heat-gelatinized starch) is

apparently the same at 90°C. as at 25° C.

(4) The continued heating of gelatinized starch pastes produces a rapid decrease in the hydration capacity. This change is much more rapid for potato starch solutions than for wheat starch solutions.

(5) Cold gelatinization of starch with chemicals is not the same phenomenon as heat gelatinization. Cold gelatinized wheat starch occupies a volume of 28 to 35 cc. per gram whereas heat gelatinized wheat starch occupies only approximately one-half this volume.

(6) The cold gelatinization of starch by chemical action appears to involve identical reactions irrespective of the chemical which is employed, e.g. NaOH, NaCNS, KCNS, sodium salicylate or urea, although the maximum hydration of the starch occurs at widely different concentrations of the chemical.

(7) Cold gelatinization of starch involves at least three different reactions. (1) At low chemical concentration no hydration takes place. (2) As the concentration is increased a rapid swelling of the intact granules occurs, resulting eventually in a rupture of the granules. (3) The individual micelles released from the starch granules continue to increase in volume (peptization) through an increasing concentration of the gelatinizing chemical.

(4) Finally, as more chemical is added, the concentration of the chemical in the dispersions medium becomes so great that a slow osmotic dehydration of the hydrated micelles takes place.

Bayfield (1934) while working with 100 experimentally milled Ohio soft winter wheat flours found that loaf volume was positively correlated with both protein content and viscosity. He concluded that since loaf volume is an acceptable measure of strength the viscosity test may offer some possibilities as a substitute for the bromate baking test for measuring strength.

Bayfield (1934), using a MacMichael viscosimeter, investigated several factors which affect the results obtained in making a viscosity determination on a flour-water suspension. It was found that flour granulation had a decided influence upon the test, particularly when no time was allowed for flour hydration between making up the suspension and running the determination. Increasing fineness of flour increased the maximum viscosity in the "no-time" tests. By digesting the suspension for one hour, however, the influence of varying flour granulation was largely eliminated.

From a series of tests when time and temperature of digestion were varied it was concluded that one hour and

30°C. gave satisfactory results. It seemed desirable to use such a digestion period in cases where a wide range in flour characteristics was expected to be encountered or in cases where protein quality alone was being determined.

Bayfield found that machine mixing of the flour-water suspensions gave more uniform results than hand mixing in a mortar and pestle.

Tests were carried out in which the use of a constant amount of protein in the sample was compared with the use of a constant flour weight sample. The results indicated that variable amounts of protein in a sample (constant flour weight) produced large differences in the viscosity results. The use of a constant weight of protein in the sample largely eliminated these differences when one variety of wheat was used. Bayfield concluded that the use of a constant weight of protein sample gave promise of giving a measure of protein quality, providing the ash content was held within narrow limits.

Reiman (1934) in an investigation undertaken to develop a reliable method for the measurement of the viscosity of flour-in-water suspensions used three methods of preparing the suspension, and three methods for measuring the viscosity. The selected method used a weight of sample equivalent

to two grams of protein. This quantity of flour is suspended in 100 cc. of water by the use of a mortar and pestle. A MacMichael viscosimeter using a No. 30 wire and a cup speed of 12 r.p.m. was suggested. A viscosity curve was obtained by measuring the viscosity of the flour-in-water suspension and then the viscosity after acidulation first with 1 cc. of N/1 lactic acid, followed by three 2 cc. portions. The difference in viscosity between successive readings is plotted against a number equal to one less than the number of the reading.

The results of his investigation showed that viscosity of flour-in-water suspensions, acidulated with lactic acid, can be used as a reliable means for determining the types and grades of wheat flours.

According to Bayfield (1935), the method of making the suspension and performing the test according to the several increment method as outlined in Cereal Chemistry 10: 494-501 has proven satisfactory for soft wheat flours in routine control work. In this procedure using (1) a constant weight of flour (20 gm. on a 15% moisture basis), and (2) a constant weight of protein (sufficient flour to equal 2 gm. protein), the constant weight of flour method was used in order to give a picture of flour characteristics "as is", while the constant weight of protein method was used as a measure of protein quality.

THEORY OF VISCOSITY

Fundamental Concepts

Viscosity may be defined as the internal friction of a liquid, the resistance to shear or flow. The unit of viscosity is the poise, so named from the Frenchman, Poiseuille, who first devised methods for the measurement of viscosity. "A poise may be defined in cgs units as the force which, when exerted on a unit area between two parallel planes one square centimeter in area and one centimeter apart, produces a difference in streaming between the two planes of one centimeter velocity per second. A centipoise, as the name implies, is 1/100 of a poise, and inasmuch as the absolute viscosity of water at 20°C. is 1.005 centipoise, the centipoise is generally used as the unit for plotting the viscosity of liquid systems. It is noted from the above definition that viscosity is expressed in absolute terms and that it is not derived from a reference liquid. There is often the general misconception that water is the reference liquid to which viscosity units are referred.

η is called the coefficient of viscosity, and is the force required per unit area to maintain unit gradient of

velocity; or it is the force required per unit area to maintain unit difference of velocity between two parallel planes in the liquid unit distance apart. The coefficient of viscosity may be defined as that force which when exerted on unit area between two parallel planes of unit area placed one centimeter apart would produce a difference in the velocity of streaming of the two planes of one centimeter per second. The coefficient is usually expressed in dynes, centimeters, and seconds, and the value of n in poises or centipoises.

The reciprocal of the viscosity is called fluidity, ϕ, and is generally expressed as $1/n$ (in poises).

Development

It is to Poiseuille (1842) that we owe our knowledge of the simple nature of flow in capillary spaces which is in contrast with the complex condition of flow in wide tubes heretofore used. He wished to understand the nature of flow of the blood in the capillaries, being interested in internal friction from the physiological point of view. He investigated the effects of (1) pressure, (2) length of capillary, (3) diameter of capillary, and (4) temperature upon the rate of flow in capillary tubes.

The equation as developed by Poiseuille was,

$$V = K \frac{pD^4t}{l}$$

in which "V" is the volume of the liquid which flowed in time "t" through a capillary whose length was "l" and whose diameter was "D", "p" being the pressure causing the flow and "K" a constant.

Poiseuille did not use the terms viscosity or fluidity; nevertheless the values of "K" are proportional to the fluidity. Poiseuille first developed from theoretical considerations his formula based on the flow of a liquid through a capillary tube, on the theory that such a column of liquid was composed of innumerable cylinders, each moving slightly faster than the other as the distance from the wall of the tube increased. Stokes (1847), and Hagenbach (1860) modified the original formula of Poiseuille to the formula now generally accepted as representing truly viscous flow.

$$n = \frac{\pi r^4 p t}{8 l V}$$

where n = coefficient of viscosity;

r = radius of the capillary;

p = hydrostatic pressure of the liquid flowing through the tube ;

t = the time necessary for the volume (V) to flow through the capillary;

l = length of the capillary.

From these two equations, Poiseuille's law is briefly, that for a given volume of liquid and a given capillary, the time of outflow will be inversely proportional to the pressure causing flow. This formula is very satisfactory for pure liquids and for truly crystalloidal solutions. Even in these cases, however, deviations from the formula may be observed at high pressures, in which case the flow is more like a solid rod of liquid being forced through without the accompanying internal friction, a film of liquid practically without motion acting as a lubricant on the walls of the tube.

In the more accurate work a correction for kinetic energy is introduced. The following equation, given by Bingham then applies:

$$n = \frac{\pi g\, r^4 p\, t}{8V\,(l + \lambda)} - \frac{M \rho\, V}{8\pi t (l + \lambda)}$$

n = coefficient of viscosity

g = gravitational constant

p = pressure

t = time in seconds

V = volume of liquid

l = length of capillary

r = radius of capillary

ρ = density of liquid

M = constant with a value 1.12 assigned by Bingham.

λ = correction to be made to the length of the capillary on account of viscous resistance outside the capillary.

The material comprising the walls of the capillary tube makes no appreciable difference in the viscosity of truly viscous systems. Apparently there is always a thin film of liquid on the surface of the capillary tube, so that friction between the liquid and the wall of the capillary does not exist. The friction is actually between the bulk of the liquid flowing through the tube and a very thin film of liquid fixed on the surface of the capillary.

Instruments Used

The capillary viscosimeter of Poiseuille (1847) was the first of this type. Of the numerous forms of capillary viscosimeters, perhaps the Ostwald type is the best known. When using this apparatus the time of outflow for a liquid whose viscosity is known must first be determined, after which the viscosity of any other liquid may be determined from the equation, knowing the time of outflow and the densities.

$$\frac{n}{n_1} = \frac{D\ t}{D_1 t_1}$$

Where n and n_1 are the viscosities of the standard and unknown liquids respectively, t and t_1 are the time of outflow, and D and D_1 are the densities.

The torsional balance type of viscosimeter was another type and appears to have been first used by Coulomb (1800). A disc, ball, or cylinder is suspended by means of a fine wire in a cylinder containing the liquid being investigated. In instruments of the Doolittle (1893) type the inner ball is usually rotated through one revolution and then released. The damping effect of the liquid on its rotation indicates the viscosity; the more the rotation is retarded, the higher the viscosity of the liquid. In instruments of the Couette (1890) type, the outer cylinder is rotated at a constant speed until the torsional force exerted on the wire by the suspended cylinder balances the viscous resistance of the liquid, and remains in a fixed position. The angular displacement is then read off on some convenient scale. In instruments of this type care is taken to eliminate the effect of the ends as in the apparatus of Hatschek (1913), thus permitting the calculation of the viscosity coefficient from the dimensions of the apparatus.

Recently torsion viscosimeters, which show particular adaptability to rapid determinations of the viscosity of industrial materials, have been perfected.

No adequate formula has been devised which expresses the viscosity of a lyophilic system. Hatschek proposed the formula,

$$n' = n \frac{\sqrt[3]{\phi}}{\sqrt[3]{\phi} - 1}$$

where n' = viscosity of the lyophilic solution;

n = viscosity of the dispersion medium;

ϕ = ratio of space occupied by the total volume of the system to the volume occupied by the disperse phase.

Hatschek states that this formula is only a first approximation. Another formula which has been suggested by Einstein is

$$n' = n(1 + K\phi)$$

where "K" is a constant.

Hatschek estimated that the constant had a value of 4.5. Einstein gave it a value of 2.5.

Kunitz has suggested that the formula is probably more accurate when expressed as,

$$n = \frac{1 + 0.5\phi}{(1 - \phi)^4}$$

and finds that this formula expresses quite accurately the relation between the volume of the solute and the viscosity of the system.

Viscosity and Plasticity

The solid line (AB) in figure 1 is a diagrammatic representation of a truly viscous system. It is noted that the increase in rate of flow with increase in force applied is a linear function which passes through the point of origin. The dotted line (CD) represents plastic flow, and it is noted that it intersects the force axis to the right of zero force. It is, accordingly, necessary that energy be added to deform the system before plastic flow begins. This amount of energy is known as the "yield value". Plasticity, therefore, differs from viscosity in that when we are dealing with plastic materials we must determine not only the rate of flow per unit of force applied, but likewise the yield value.

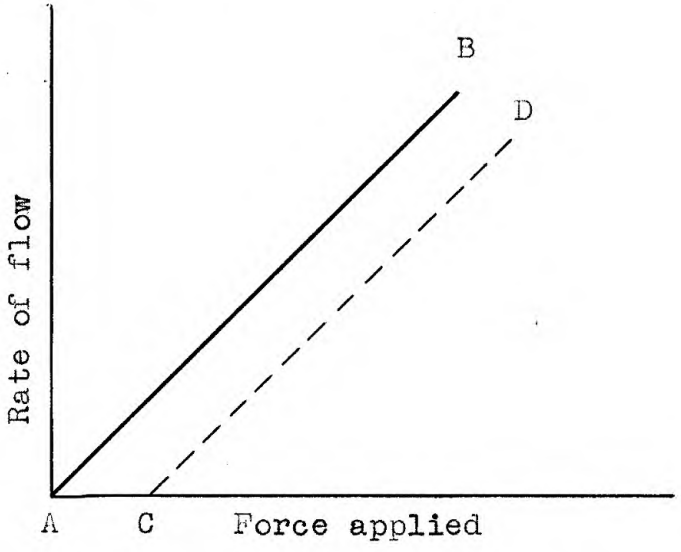


Figure 1 - Showing diagrammatically the relation between true viscosity and plasticity. AC is the "yield value" of the plasticity formula.

Colloid systems show a wide range in viscosity or plasticity. In general the lyophobic solutions exhibit a viscosity which approaches very closely to the viscosity of the pure dispersion medium, and which increases only slightly with increasing concentration of dispersed material. On the other hand, lyophilic systems may reach very high values for viscosity, and many lyophilic sols and gels are truly plastic and have relatively high yield values. With lyophilic systems, there is not a linear relationship between viscosity or plasticity and the concentration of a disperse phase but instead a parabola, such as is shown diagrammatically in figure 2. This is undoubtedly due to the fact that the lyophilic systems are solvated, and accordingly the particle has associated with it a larger or smaller amount of the dispersion medium, so that the actual amount of the dispersion medium is

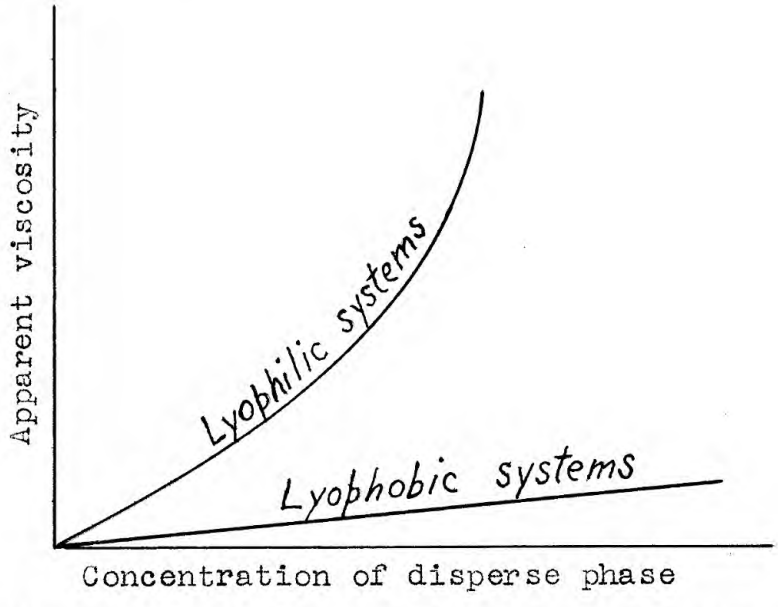


Figure 2 - A diagrammatic representation of the relation between viscosity and concentration in lyophobic and lyophilic systems.

decreased with each added increment of disperse phase.

Factors Which Influence Viscosity of Colloidal Systems

In general the viscosity of colloid systems decreases as temperature increases. This is due in part to the effect of temperature on the dispersion medium. Water, for example, has a viscosity of 0.2838 centipoise at 100°C., whereas at 0°C. it has a viscosity of 1.7921 centipoise. Here the viscosity has increased approximately 800 per cent from 100° to 0°.

Also with colloid systems, viscosity changes due to temperature are influenced not only by the viscosity of the dispersion medium but likewise by the effect of temperature on solvation. Most lyophilic colloids are more highly solvated at the lower temperatures. Gelatin and agar, for example, form relatively non-viscous sols at the higher temperatures but set to more or less rigid or plastic gels at the lower temperatures. Starch, on the other hand, forms a more or less lyophobic suspension at the lower temperatures, and the temperature may be increased appreciably without great changes in viscosity until a critical temperature known as the gelatinization point is reached. At this critical point the starch granules undergo rapid hydration and the extremely viscous or plastic starch paste

results. An increase in temperature past this point results in a decreased viscosity or plasticity.

Time may have a great effect on viscosity or plasticity of colloidal systems whereby the change in viscosity is associated with the increase or decrease in the solvation of the micelles.

Electrolytes may greatly alter the viscosity of lyophilic systems, in some instances causing relatively enormous changes. In order for such results to be manifest, it is essential that colloid systems be as nearly as possible electrolyte-free. Sharp and Gortner found that there was an enormous decrease in the viscosity of an acidulated wheat flour-water system on the addition of a trace of the salt of a bivalent metal.

The viscosity of a crystalloidal solution of a given solute in a given solvent is determined solely by the concentration and the temperature at which the measurement is made. Ostwald (1913) pointed out that this is not true for lyophilic colloid systems in which there are ten factors which must be taken into consideration: (1) concentration, (2) temperature, (3) degree of dispersion, (4) solvation, (5) electrical charge, (6) previous thermal treatment, (7) previous mechanical treatment, (8) the presence or

absence of traces of other lyophilic colloids, (9) the age of the lyophilic sol, and (10) the presence of both electrolytes and non-electrolytes. Sharp and Gortner have pointed out that another factor of extreme importance should be added to this list, i.e., the rate of shear. It is evident from the above list of variables that the study of viscosity or plasticity in lyophilic systems presents experimental difficulties. Viscosity and plasticity methods, on the other hand, afford one of the most valuable tools available to the colloid chemist.

Nature of Viscosity Changes Induced by Addition of Acids and Alkalies to Flour Suspensions

According to Loeb's hypothesis, in order that viscosity changes may take place, there must first be a chemical combination of the acid with the protein, followed by the ionization of the protein salt and the subsequent hydration of the protein ion through osmotic behavior controlled by the Donnan equilibrium. Loeb apparently takes the view that imbibition changes in a protein system are due to chemical reactions, whereas the prevalent viewpoint of workers in the field of colloids is that they are due to surface phenomena. Enormous viscosity increases of 300 to 400 degrees MacMichael are produced when flour-water suspensions are treated with as small an amount as 0.4 cc.

of normal lactic acid, the change being produced almost instantaneously. It appears very improbable that equilibrium would be reached practically instantaneously if osmotic phenomena are involved. On the addition, however, of 0.1 cc. of a normal salt solution such as magnesium sulfate to such a system, the viscosity fell practically instantaneously to a small fraction of its former value obtained by treatment with lactic acid. In this case, also, the rapidity of the changes is not suggestive of osmotic behavior. The more probable viewpoint of the workers in the field of colloids is that the changes are due to surface phenomena. According to this idea, viscosity changes on the addition of acid and salt may be likened to the changes which take place when an electric current is passed through an electro-magnet suspended above a pile of iron filings and the current is later broken by throwing the switch. On the addition of the lactic acid a comparatively thick "shell" of water, apparently, is bound upon the surface of the glutenin particle, only to be instantly released when the salt is added. If the water, on the other hand, penetrated into the interior of the glutenin particle by osmosis, there should be a gradual fall in viscosity when dehydration takes place. The idea of surface phenomena seems much more probable from the above evidence.

EXPERIMENTAL

The Problem

The object of this investigation was to determine the value of viscosity as a measure of quality in flour produced from different wheat varieties by comparing the viscosity curves obtained with the baking value of the respective flours, using other physical and chemical tests on each flour to give any definite physical or chemical weaknesses which might be responsible for discrepancies in their correlation.

In this investigation no attempt was made to investigate the factors which might influence the viscosity curves of flour-in-water suspensions but rather to determine each flour's respective curve under as nearly as possible the same conditions and then see what correlation, if any, could be derived between the viscosity measurements and the baking value of each flour.

The measurements obtained in this work are to the greatest extent a measure of the imbibitional capacity of the flour constituents in a state of coarse suspension as shown by the resistance of each flour suspension to the shearing force applied after each successive increment of N/10 lactic acid was added.

In this work no attempt was made to distinguish between viscosity and plasticity or to determine the plasticity constants for those mixtures which were undoubtedly plastic. The term "viscosity" has been used in a rather loose sense throughout to indicate all resistance offered by the suspensions to the applied shearing force.

Flours Used

In this work 98 wheat samples were obtained from the 1936 crop grown in different sections of the state of Kansas. The samples numbered from 21925 to and including 21958 were the A.L. Clapp cooperative wheat varieties which were obtained from five different sections of Kansas. The sections represented were south-central, north-central, central, eastern, and northeastern. The samples numbered from 21959 to 21995 inclusive were the H.H. Laude varieties grown on the Kansas State College agronomy farm plots. Those included between 22000 and 22008 were the A.F. Swanson varieties grown at the Hays Experiment Station. J.H. Parker submitted the samples included between the numbers 22009 and 22011 which were grown in northwestern Kansas. The samples numbered from 22012 to 22026 inclusive were Kansas State College nursery varieties grown by J.H. Parker.

Each of the above wheat samples was milled on the Kansas State College experimental mill and the straight flour from each was used for the different tests in this work.

Chemical and Physical Analysis of Flours

Moisture. The vacuum method based on the official Association of Official Agricultural Chemist method as given in "Cereal Laboratory Methods" was used.

Ash. The American Association of Cereal Chemists' direct weighing method given in "Cereal Laboratory Methods" was used.

Protein. The American Association of Cereal Chemists' method for determing total crude protein as given in "Cereal Laboratory Methods" was used.

Maltose. The Blish-Sandstedt method as given in "Cereal Laboratory Methods" was used.

Absorption. The principle of this procedure was to treat the sample of flour with a large excess of water, mix well, and allow to stand for sufficient time to permit each particle to be thoroughly soaked and then remove the excess of water by centrifuging the mixture in a small Sharples super centrifuge running at 1500 r.p.m. The bowl

containing the dough was then weighed and the increase in weight over the weight of the bowl and the dry flour was considered to be due to absorbed water. These results may be duplicated within 0.2 of one per cent if all variables are kept constant.

Water and glassware used in the determination remained in a water bath at 27°C. until ready for use. In the determination 100 grams of flour (15 per cent moisture basis) were weighed out and after being placed on top of 500 cc. of water were mixed by means of a malted milk mixer for two minutes. The material on the mixer was washed into the beaker which along with its contents was allowed to stand in the water bath for five minutes. After the centrifuge had attained a constant speed, the flour-in-water suspension was poured in, after which the material sticking to the policeman and sides of the beaker were washed into the feeding funnel which was then flushed with 60 to 80 cc. of water. The centrifuging was continued for one minute after the last water had left the funnel. Immediately after the centrifuge had coasted to rest, the bowl with its contents was weighed and the amount of absorbed water determined.

Gas Production and Gas Retention. A brief description of the device used for measuring the rate of gas production and rate of gas retention in the dough prepared from the flour milled from each variety is given below. The container for the dough, which rested on a watch glass, was a wide mouth screw clamp Mason fruit jar. For the top glass plate originally used with the fruit jar was substituted a brass disc 1/8 inch thick and exactly the same diameter as the glass plate so as to fit the top rim of the jar. Through the center of this brass plate was soldered a brass pipe 1/4 inch outside diameter and 1/8 inch inside diameter and about 5½ inches in length so that when the brass tube was in position it extended to near the bottom of the 300 cc. filter flask. Over this brass tube was fitted a rubber stopper of such size as to fit the mouth of the flask when its top rim came near the brass plate. In order that there might be an air tight fit between the brass plate and the top rim of the jar, a rubber ring with outside diameter slightly larger than that of the disc was used.

The dough for each determination was prepared by mixing in a micro-mixer 10 grams of flour (15 per cent moisture basis) with 5 cc. of the yeast solution and that amount of water which gave each flour the absorption as indicated by the super centrifuge. The yeast solution was

prepared by suspending 10 grams of yeast in 90 cc. of water.

For measuring the rate of gas production no absorption of CO_2 took place, while in measuring the gas retention all escaping CO_2 was absorbed before it accumulated sufficiently to create a pressure. In both measurements the humidity in each jar was approximately 90 per cent. This was obtained by having 20 cc. of a 10 per cent NaCl solution in the bottom of the jar for gas production and 20 cc. of a 10 per cent KOH solution for gas retention.

In the measurement of gas production the filter flask was filled almost to the level of the brass rod with water saturated with CO_2 at the temperature of the determination. As soon as gas escaped from the dough and as the dough expanded, a pressure was produced, thus forcing the water from the filter flask through the glass tube and into the 100 cc. graduated cylinder. The water was eliminated from the bottom of the filter flask and through the glass tube, the opening of which rested on the top of the graduated cylinder at approximately the water level in the flask. The rate of gas production was obtained by reading the amount of water in the cylinder at intervals of ten minutes. Each flour's gas production in cc. given in Table I was obtained after 160 minutes of fermentation at 27°C.

In the measurement of gas retention, ordinary distilled water was used in the filter flask. The escaping CO_2 was absorbed almost completely by the 10 per cent KOH solution in the bottom of the jar. A sponge containing a 1 per cent KOH solution was held up against the brass plate so that the opening of the brass pipe was covered. The rate of gas retention was obtained by reading the amount of water in the cylinder at intervals of 10 minutes. Each flour's maximum gas retention given in Table I was obtained at the exact minute CO_2 started to escape from the dough more rapidly than it was produced, with the result that the water receded in the glass tube.

Both units of the apparatus were contained in a cabinet at 27°C. (±0.1). The apparatus was assembled sometime before the dough was put in so that conditions of equilibrium were attained. In order that the humidity conditions in the jar would be disturbed as little as possible, the jar was opened for the insertion of the dough in a cabinet where the air was about saturated with water vapor at 27°C.

Doughball. This test, often referred to in the literature as the "wheat meal fermentation time test", is used to some extent by the plant breeder in selecting wheat varieties because of its value as a genetic test. The principles of the procedure are given below.

The wheat was ground to pass a 40 wire sieve by means of a burr mill. The meal was tested within 24 hours after being ground. After mixing the meal with a spatula, 15 grams (enough for triplicate 5 gram dough balls) were weighed out for testing.

Several hours before making the determination, however, three glasses (each with a capacity of 270 cc.) for each test were almost filled with distilled water at about 30°C. and placed in an accurately controlled cabinet at 30°C. (±0.1). A yeast suspension was then prepared by suspending 20 grams of Fleischmann's yeast in 228 cc. of distilled water and placed in the cabinet until ready for use.

Fifteen grams of the meal were placed in the micro-mixer and by means of a pipette 9.4 cc. of the well mixed yeast suspension were added. Each dough was mixed to the point at which all ingredients were completely incorporated. In case of wheats which were unusually dry or which had a high absorption, it was necessary to add from 0.5 to 3.0 cc. of distilled water by means of a syringe during the mixing. The time of mixing varied from 50 to 180 seconds depending on the variety or strain. After removing the dough from the mixer, it was shaped into a cylinder and divided into three approximately equal parts each of which was rolled into a smooth sphere by rolling 25 times between the palm of the hands.

Each ball was placed in a glass containing 190 cc. of distilled water at 30°C. (±0.1) whereby the ball fell to the bottom of the glass. The time of immersion of the triplicates was recorded as the time of starting the test.

As soon as fermentation had continued for a few minutes, the ball became buoyant and rose to the surface of the water. The ball continued to swell, thus acquiring a larger volume. In case of wheats with a short time (25 to 40 minutes), disintegration occurred while the ball was in a spherical or slightly flattened spherical form. As the disintegration time increased, the ball assumed a more flattened appearance and still later on if disintegration had not occurred, it assumed the shape of a solid doughnut. In any case when the ball started to detach itself in one way or another and fell to the bottom of the glass, the time was again recorded as the time of disintegration from which the length of time to disintegrate was calculated.

Table I Chemical and physical analysis of flours

Mill No.	Variety or description of wheat ground	Section of Kansas grown	Per cent moisture	Per cent ash 15% moisture	Per cent protein 15% moisture	Maltose mg./10 gm.	Per cent absorption As rec'd.	Per cent absorption 15% moisture	Gas production cc.	Gas retention cc.	Time to recede	Doughball time in min. (on meal)
21925	Kanred	S.Central	13.28	.451	11.57	151	65.6	62.3	69.5	46.0	124	55
21926	Turkey	" "	13.50	.452	11.10	117	61.7	58.9	55.0	34.5	100	63
21927	Tenmarq	" "	12.89	.433	11.61	135	64.8	61.1	64.5	38.0	95	120
21928	Blackhull	" "	13.00	.440	11.68	109	61.2	57.7	52.0	34.0	129	62
21929	Early Blackhull	" "	13.27	.426	12.11	75	58.6	55.5	39.0	25.5	133	57
21930	Quivira	" "	12.84	.460	12.48	151	67.6	63.4	69.5	44.5	116	48
21931	Kanred x Rd. Fed.	" "	13.12	.438	12.28	120	64.5	61.0	50.5	35.5	129	110
21932	" " " "	" "	12.70	.382	11.64	107	64.4	60.3	45.5	30.5	124	64
21933	Kanred	N.Central	12.43	.505	13.83	137	70.5	65.6	71.5	48.0	132	52
21934	Turkey	" "	12.32	.477	13.38	123	68.3	63.4	66.0	43.5	125	86
21935	Tenmarq	" "	12.05	.497	12.82	179	75.9	69.4	89.0	59.0	131	143
21936	Blackhull	" "	10.37	.455	12.85	157	71.2	62.4	75.5	50.0	130	55
21937	Early Blackhull	" "	10.79	.431	12.81	145	69.5	61.7	65.5	44.5	129	47
21938	Tenmarq	Central	11.48	.443	10.56	148	68.6	61.9	70.0	45.5	131	110
21939	Kawvale	"	11.86	.438	11.87	166	69.6	63.5	72.5	44.5	116	63
21940	Fulcaster	"	10.75	.387	11.76	97	61.5	54.0	60.0	26.5	82	43
21941	Clarkan	"	11.76	.382	11.90	73	61.3	55.5	48.5	30.0	101	43
21942	Harvest Queen	"	11.93	.361	11.72	72	58.4	53.0	40.0	24.5	122	41
21943	Turkey	Eastern	12.91	.404	8.39	130	65.5	61.6	57.5	33.5	105	52
21944	Tenmarq	"	11.63	.427	9.90	146	68.8	62.4	63.5	34.0	100	94
21945	Blackhull	"	11.88	.390	10.03	98	59.2	53.8	46.5	28.5	116	46
21946	Kawvale	"	11.56	.396	9.37	152	66.9	60.5	63.5	38.0	108	53
21947	Fulcaster	"	12.99	.379	9.57	98	69.4	53.9	42.5	27.5	88	37
21948	Clarkan	"	13.07	.364	10.27	62	60.6	57.0	38.0	23.0	108	42
21949	Harvest Queen	"	12.50	.350	9.86	66	55.2	50.8	34.0	20.5	77	37
21950	Turkey	N. East	12.85	.431	9.95	146	65.8	61.9	65.0	33.0	92	57
21951	Tenmarq	" "	12.25	.436	9.50	170	70.1	65.0	70.0	41.5	108	101
21952	Blackhull	" "	13.02	.403	9.82	114	62.5	57.6	52.5	38.0	133	48
21953	Kawvale	" "	13.27	.427	9.61	146	65.0	61.8	65.0	41.0	115	49
21954	Fulcaster	" "	12.57	.397	8.95	98	57.6	53.3	49.0	24.0	76	39

Table I Continued

21955	Clarkan	N. East	12.16	.374	9.92	84	63.4	58.3	50.0	32.0	97	38
21956	Harvest Queen	" "	12.95	.367	10.00	72	53.9	50.5	38.0	20.5	76	36
21957	Michigan Wonder	" "	13.35	.357	9.32	70	53.2	50.4	42.0	17.5	52	41
21958	Iobred	" "	13.00	.385	9.28	114	59.6	56.4	51.5	33.0	105	51
21959	Turkey	Ag. Farm	12.25	.390	11.19	114	61.8	56.9	51.0	32.0	144	46
21960	Early Blackhull	" "	12.48	.348	11.60	92	58.2	53.7	47.0	30.0	140	41
21961	Kanred x Hd. Fed.	" "	13.12	.338	10.51	130	60.7	57.4	53.5	35.5	108	104
21962	" " " "	" "	13.29	.341	10.49	116	65.8	59.8	46.5	31.5	141	55
21963	Turkey Selection	" "	11.80	.409	10.55	130	62.6	56.9	56.0	38.0	129	40
21964	Blackhull	" "	13.14	.354	11.40	82	56.9	53.7	43.5	30.5	120	41
21965	Turkey Selection	" "	12.67	.349	10.65	104	56.2	52.2	46.5	29.5	136	61
21966	Kharkof	" "	13.75	.357	11.09	100	64.0	61.4	47.0	31.0	140	46
21967	Nebraska No. 60	" "	13.43	.349	9.76	98	60.2	56.1	46.0	31.5	136	39
21968	Oro	" "	12.22	.399	10.36	113	63.3	58.4	52.0	34.0	113	99
21969	Kawvale	" "	13.29	.384	10.78	124	63.7	60.5	57.5	38.5	123	45
21970	Fulcaster	" "	12.83	.347	10.53	70	55.4	51.6	38.0	25.0	92	37
21971	Kan. x Genesse Giant	" "	12.80	.335	10.04	72	56.9	53.1	37.5	26.5	93	40
21972	Clarkan	" "	12.55	.331	10.54	62	60.8	56.4	35.5	22.5	116	38
21973	Harvest Queen	" "	13.16	.329	10.42	56	57.7	54.5	32.0	21.0	126	40
21974	Chiefkan	" "	13.41	.389	10.89	163	70.2	65.8	71.5	50.0	124	30
21975	Kanhull	" "	13.35	.385	11.44	130	63.8	60.8	59.0	43.0	133	38
21976	Rupp	" "	12.10	.367	11.08	89	59.6	54.5	49.5	34.0	135	37
21977	Oro x Tenmarq	" "	13.48	.375	11.15	131	67.1	64.3	57.0	39.0	140	129
21978	" " "	" "	13.37	.406	11.39	142	68.3	65.2	62.5	43.0	143	118
21979	Kanred x Hd. Fed.	" "	13.26	.353	10.39	157	66.5	63.2	62.5	43.0	146	65
21980	" " " "	" "	12.88	.347	10.39	163	66.6	62.7	60.5	42.5	144	87
21981	" " " "	" "	12.55	.420	10.35	158	67.3	62.7	62.0	40.0	112	103
21982	" " " "	" "	12.42	.415	10.29	160	66.4	61.7	61.5	41.5	116	110
21983	Kawvale x Tenmarq	" "	11.97	.352	10.43	203	72.4	66.7	81.0	52.5	139	43
21984	" " "	" "	12.72	.343	10.22	157	67.6	63.3	66.5	34.5	97	130
21985	" " "	" "	12.25	.351	10.27	178	72.7	67.5	76.5	37.0	99	132
21986	" " "	" "	12.84	.316	10.48	167	70.4	66.4	70.0	49.0	122	60
21987	P-1066 x Prelude	" "	12.26	.422	11.82	179	70.7	65.5	73.5	48.0	123	46
21988	Quivira	" "	13.88	.426	10.70	167	69.6	67.4	72.5	50.5	125	56
21989	Prelude x Kanred	" "	13.17	.531	11.60	199	75.2	71.6	81.5	55.5	147	47
21990	Kan. x Marquis	" "	13.20	.427	10.67	150	69.4	65.9	69.0	46.0	124	139
21991	Tenmarq	" "	11.55	.383	10.38	152	69.3	62.9	71.0	45.0	110	77
21992	Kanred	" "	12.67	.382	11.20	126	64.1	59.9	59.5	37.5	135	52

Table I Continued

21993	Cheyenne	Ag. Farm	11.35	.384	9.54	125	65.1	58.5	49	23.5	87	125
21994	Kan. x Hd. Fed.	" "	12.80	.353	10.48	154	67.6	63.5	60	37.5	130	109
21995	Kawvale x Tenmarq	" "	12.79	.355	9.75	187	75.5	71.2	78	32	84	187
22000	Early Blackhull	Hays	12.97	.369	12.60	93	59.2	55.5	49	34	125	44
22001	Quivira	"	12.49	.472	13.06	212	76.6	71.6	93	54	115	46
22002	Kan. x Hd. Fed.	"	12.36	.450	12.52	219	72.5	67.8	85.5	48.5	110	101
22003	Blackhull	"	11.84	.549	12.67	141	63.8	58.0	70.5	44	107	37
22004	Chiefkan	"	11.41	.504	12.14	320	90.8	83.3	132	74.5	149	31
22005	Tenmarq	"	11.64	.519	13.51	230	81.1	74.2	101.5	58	120	144
22006	Kanred	"	12.09	.493	13.20	141	69.7	64.2	79	41.5	97	39
22007	Cheyenne	"	11.48	.497	13.35	162	73.9	67.1	82.5	34.5	68	197
22008	Turkey	"	12.02	.514	13.23	148	71.3	65.6	73.5	35.5	78	43
22009	Tenmarq	"	12.12		12.91	183	75.1	69.5	90.5	49	101	184
22010	Kanred	"	11.30		14.47	219	86.9	79.4	106	48.5	105	45
22011	Blackhull	"	11.80		10.70	179	74.2	66.1	82	53	110	39
22012	Tenmarq	Parker N.S.	13.15	.499	12.73	125	66.0	62.6	60.5	41.5	125	100
22013	Turkey	" "	11.68	.387	11.89	124	64.8	58.5	57.5	39	112	55
22014	Turkey Sel.	" "	12.20	.370	13.07	128	64.3	59.2	52	36	138	71
22015	Turkey Sel.	" "	12.00	.367	13.04	133	64.4	58.9	54	36	145	79
22016	Oro x Fulhard	" "	12.10	.391	12.32	208	73.5	67.9	81	50.5	117	59
22017	Kawvale x Tenmarq	" "	12.28	.341	11.77	176	70.9	65.7	79.5	55.5	137	52
22018	Minturki x B.H.	" "	13.01	.340	12.85	90	59.1	55.5	53	37.5	127	43
22019	Kan. x Marquis	" "	12.86	.367	13.42	128	69.1	65.1	60	41.5	130	74
22020	Kan. x (Marq. x Kan.)	" "	12.82	.349	12.23	140	64.9	61.0	66.5	47	134	50
22021	Quivira x Tenmarq	" "	11.90	.429	12.21	200	74.6	68.6	83.5	38.5	98	101
22022	" "	" "	11.60	.381	12.93	197	75.2	68.5	84.5	57.5	142	110
22022A	Wheat x Rye	" "	11.10				67.5	60.5	89	44	98	
22023	Penquite	" "	11.49	.377	13.11	87	64.8	58.4	46.5	33.	102	43
22024	Turkey Sel.	" "	12.78	.413	13.06	168	70.6	66.6	64	44.5	130	72
22025	Minhardi x Minturki	" "	12.17	.372	12.68	173	72.9	67.5	67.5	47	134	38
22026	Turkey x Marquis	" "	11.76	.414	12.47	184	72.6	66.4	76	51	120	54

Baking Analysis of Flours

Numerous workers have investigated almost every known physical and chemical property of flour with the hope that a correlation might be found to exist with flour quality or with the ability of the flour to bake a desirable loaf of bread. After all, if a flour will not produce a good loaf of bread after various treatments, it is surely not of the desired quality as a bread flour according to the present methods used in baking.

In most work of this nature where the quality of different flours was being determined, as fixed a method as was available was used. In other words, all flours were placed under identical conditions which were not necessarily ideal for each particular flour. It seems that an exact but not a fixed method for baking different flours should be employed with the purpose of baking each flour under conditions that would permit each to display its value as a bread flour.

The method of baking used in determining the quality of the numerous flours tested in this investigation was intended to place each flour under baking conditions desired as indicated by the "stop and go signs" manifested by each flour during the bake. The procedure used in baking each flour is given below.

Method. All ingredients for the baking of each flour were prepared, using a 75 per cent sponge. Three hundred grams (15 per cent moisture basis) of each flour being tested were weighed out for the sponge; and 100 grams (15 per cent moisture basis) of each were weighed out for the dough flour. The super centrifuge was used for determining each flour's absorption, the values of which are given in Table I. The other ingredients used with each flour are listed below.

Ingredients in Sponge	Ingredients in Dough
3 per cent shortening	5 per cent sugar
1.75 per cent yeast	2 per cent salt
0.25 per cent yeast food	

The sponge ingredients were mixed to a smooth consistency and brought out of the mixer at 68 to 72°F.

The sponge was placed in a crock to ferment at 80°F.

When the sponge dropped, it was removed from the crock and mixed with the dough ingredients in the Swanson recording dough mixer to a smooth and elastic consistency, the length of mixing time depending on the particular flour being mixed.

The dough was removed and scaled into four 165 gram doughs which were given 30, 45, 60, and 75 minute dough times respectively and then punched.

Each 165 gram dough was panned 15 minutes after punching.

The panned doughs were allowed to proof at 95°F. until they had received sufficient proof time as indicated by touch and appearance.

The doughs were then baked in the oven for 25 minutes at 420°F.

The bread was removed from the oven, after which the weight and volume were determined.

About 15 hours later, each group of four loaves representing each flour was scored according to the values recommended by the American Institute of Baking. Each total score in Table II represents the best loaf out of the four loaves baked from each flour. The standard used is as follows:

Volume	10
Crust color	8
Symmetry of form	3
Evenness of bake	3
Character of crust	3
Break and shred	3
Grain	10
Color of crumb	10
Flavor	15
Taste	20
Texture	15
	100

Table II Baking analysis

Mill No.	Sponge		Dough			Spec. vol.	Crumb color (10)	Ferm. tolerance (min.)	Outside type	Inside type	Total score
	Mix time (min.)	Ferm. time hr.,min.	Mix time (min.)	Ferm. time (min.)	Proof time (min.)						
21925	2.0	4:00	4.5	40	55	4.18	10	15	G	6	86
21926	2.5	4:00	6.0	45	55	4.46	10	15	G	5	87
21927	2.5	4:00	8.0	40	55	4.34	10	15	F	7	81
21928	(Not enough flour.)										
21929	1.75	4:00	3.0	30	55	3.68	10	15	H	3	78
21930	1.75	4:00	3.5	40	55	4.22	10	15	G	4	78
21931	2.75	4:00	6.0	20	55	4.78	10	30	F	5	96
21932	2.25	4:00	4.5	10	55	3.98	10	15	F	7	99
21933	1.5	4:00	4.5	50	55	4.08	10	30	G	5	83
21934		4:00	5.5	50	55	4.28	10	45	G	6	91
21935	2.25	3:00	6.5	50	55	4.83	9	15	F	5	97
21936	1.75	3:05	3.0	30	55	3.88	5	15	J	3	73
21937	1.5	3:00	2.0	60	55	4.30	7	15	H-	4	86
21938	3.0	3:30	6.0	60	67	4.64	8	15	F	5-	90
21939	2.0	3.00	4.0	40	60	4.24	3	30	J	4	76
21940	2.0	3:15	3.1	40	63	4.10	6	15	H-	4	81
21941	1.25	4:10	1.4	40	63	4.50	4	15	J	3	76
21942	1.25	4:15	2.1	30	45	3.90	10	30	H-	5	85
21943	3.0	3:05	12.0	60	89	4.22	2	30	H-	5	87
21944	3.25	4:00	13.0	50	80	4.07	10	30	J	6+	88

Table II Continued

21945	2.5	4:25	4.0	70	80	4.38	8	15	F-	6	92
21946	2.5	3:05	8.9	70	72	4.35	8	30	H	5	94
21947	1.5	3:45	7.0	85	65	4.09	7	15	J	6+	85
21948	1.25	3:45	3.0	70	62	4.36	7	60	G	6	88
21949	2.25	3:40	3.0	70	65	4.24	7	15	H	6	86
21950	3.5	3:25	12.2	50	58	3.93	9	15	J	4	80
21951	3.5	3:40	16.0	50	78	3.61	10	30	J	6+	87
21952	2.25	3:15	4.1	70	85	4.20	8	15	J	4	81
21953	2.25	4:25	6.8	60	65	3.86	6	15	J+	5	86
21954	2.25	4:25	4.0	60	60	4.03	8	45	H+	6-	88
21955	1.25	5:25	2.9	60	50	4.32	8	15	F	6-	92
21956	1.75	5:40	3.0	60	50	4.21	10	45	H	6+	94
21957	2.25	5:05	4.5	60	55	4.50	10	30	F-	6+	98
21958	2.0	4:45	4.2	45	60	4.71	6	15	F-	6+	96
21959	2.0	4:30	4.0	60	60	4.75	8	15	F-	7	93
21960	1.5	4:00	2.0	45	60	3.84	7	15	J	4	80
21961	2.5	5:40	5.0	45	60	4.93	10	30	G+	5	98
21962	2.25	4:40	6.0	15	75	4.69	9	15	G-	4	88
21963	1.5	3:25	3.0	60	70	4.48	6	15	G+	6	87
21964	1.5	3:50	2.5	60	70	4.48	5	30	F-	6	87
21965	2.5	4:30	4.0	15	75	5.10	6	30	F	6-	92
21966	1.5	3:50	5.0	60	70	5.05	4	15	H	3	82
21967	1.75	4:25	4.1	30	75	4.22	5	15	H+	6	84
21968	2.5	4:55	11.0		80	4.60	7	30	G	6	89
21969	2.0	4:30	3.8		65	4.48	10	30	G+	5-	94
21970	1.75	4:20	2.2		70	4.48	10	15	F-	6	92
21971	1.5	4:35	2.2		80	4.66	8	15	F-	7	89
21972	1.25	4:55	1.9		70	4.51	10	15	G	4	88
21973	1.5	4:55	1.8		75	4.28	10	45	F-	4	87
21974	1.25	3:15	2.0		65	3.77	9	30	J	4	81

Table II Continued

21975	1.75	3:15	3.0		65	4.94	7	15	F	7	93
21976	1.5	3:55	2.0		75	4.61	8	15	H-	7	91
21977	2.5	5:00	8.1	60	65	4.74	8	15	H+	3+	84
21978	2.0	4:00	5.0	45	60	4.69	8	15	F-	7	91
21979	2.0	4:15	5.2	60	60	4.35	6	15	H	6-	88
21980	2.0	4:45	6.5	30	57	4.64	7	15	H+	6	88
21981	2.0	4:25	7.5	45	56	5.15	7	15	F-	7	91
21982	2.25	4:00	6.5	60	60	5.14	7	30	F-	5	97
21983	1.5	3:30	4.5	60	45	4.10	7	15	H+	4	81
21984	2.5	5:00	11.5	60	60	4.49	7	15	F-	6	88
21985	2.75	5:10	14.0	15	55	4.26	7	30	F	6-	87
21986	2.0	4:20	6.2	15	52	3.98	7	15	J	4	78
21987	1.75	3:45	4.5	45	50	4.68	7	30	H	6	87
21988		3:45	6.1	45	53	4.43	7	45	H	6-	86
21989	1.5	3:55	6.0	60	55	3.92	5	15	J	3+	73
21990	2.0	4:25	8.5	45	55	4.24	7	15	J	4	80
21991	2.0	4:30	8.6	60	70	4.07	9	15	H+	6	86
21992	1.5	3:35	3.1	60	50	4.22	7	15	J+	6+	83
21993	3.0	5:20	13.5	30	55	4.38	9	30	F	5	96
21994	2.0	4:45	7.0	15	58	4.82	9	15	F	6	92
21995	2.25		9.0	15	60	3.83	9	30	J	3+	77
22000	2.35	5:45	1.25	75	40	3.89	8	15	H	4	84
22001	1.25	4:15	2.50	60	50	4.01	8	15	F-	6	90
22002	1.75	3:50	4.00	75	50	4.53	8	15	F	7	92
22003	1.25	3:25	2.00	75	65	4.39	8	15	F-	4	88
22004	1.00	4:15	2.50	75	45	3.47	8	30	J	3	78
22005	1.75	4:20	4.00	60	55	4.05	8	30	J+	6	86
22006	1.25	4:25	1.50	60	55	3.9	8	45	J	4+	82
22007	2.50	4:25	4.50	60	45	4.09	8	15	J	5-	92
22008	1.50	3:20	2.75	60	55	4.31	8	15	J+	4-	84

Table II Continued

22009	(Not baked.)										
22008	"	"									
22011	"	"									
22012	1.75	4:10	4.5	15	55	4.69	8	15	G+	6	87
22013	2.0	4:15	6.0	60	55	5.39	8	30	F-	5	98
22014	2.0	4:45	3.0	60	50	5.10	9	15	F	5	98
22015	2.0	4:45	3.2	60	45	5.07	9	30	G+	5	96
22016	2.25	4:05	7.0	45	45	4.37	9	15	G+	4	83
22017	1.5	3:40	3.1	60	55	4.58	10	45	G+	5	94
22018	1.5	5:00	2.1	60	50	4.02	8	45	J	4	79
22019	1.5	4:20	3.1	45	55	5.35	9	15	F	2+	86
22020	1.75	3:35	3.1	30	55	4.88	9	15	F-	6	91
22021	2.0		7.0	15	52	4.47	9	15	J+	4+	84
22022	2.5		3.8	45	56	5.52	7	15	F-	3+	85
22022A	(Not baked.)										
22023	"	"									
22024	"	"									
22025	"	"									
22026	"	"									

To avoid inconsistency in personal judgment, the outside type and inside type of each loaf was recorded after comparison with the photographs of loaf standards presented in Cereal Chemistry 5: 289-96.

Viscosity Titration Curves

Instrument Used. A modified Wallace-Tiernan viscosimeter as shown in figure 3 on the next page was used in determining the viscosity curve of each flour. The bowl of this instrument rotated at 20 r.p.m. It was found that a reading of 4 degrees on this instrument was equivalent to 1 degree on an improved MacMichael which used a 27 wire and rotated at 20 r.p.m.

Method and Observations. The first phase of the work on viscosity was spent in determining the approximate amounts of flour and water to use in each determination. Two flours giving different type curves were chosen for this purpose. Viscosity curves were then run using 20, 22.5, 25, 27.5, and 30 grams of each flour in 100 cc. of distilled water. Twenty-five grams of flour in 100 cc. of distilled water gave the most desirable curve.

In the actual determination, however, the exact amount of flour and water used for each flour's curve was determined individually. The flour was weighed out to 25 grams on the 15 per cent moisture basis. The amount of water

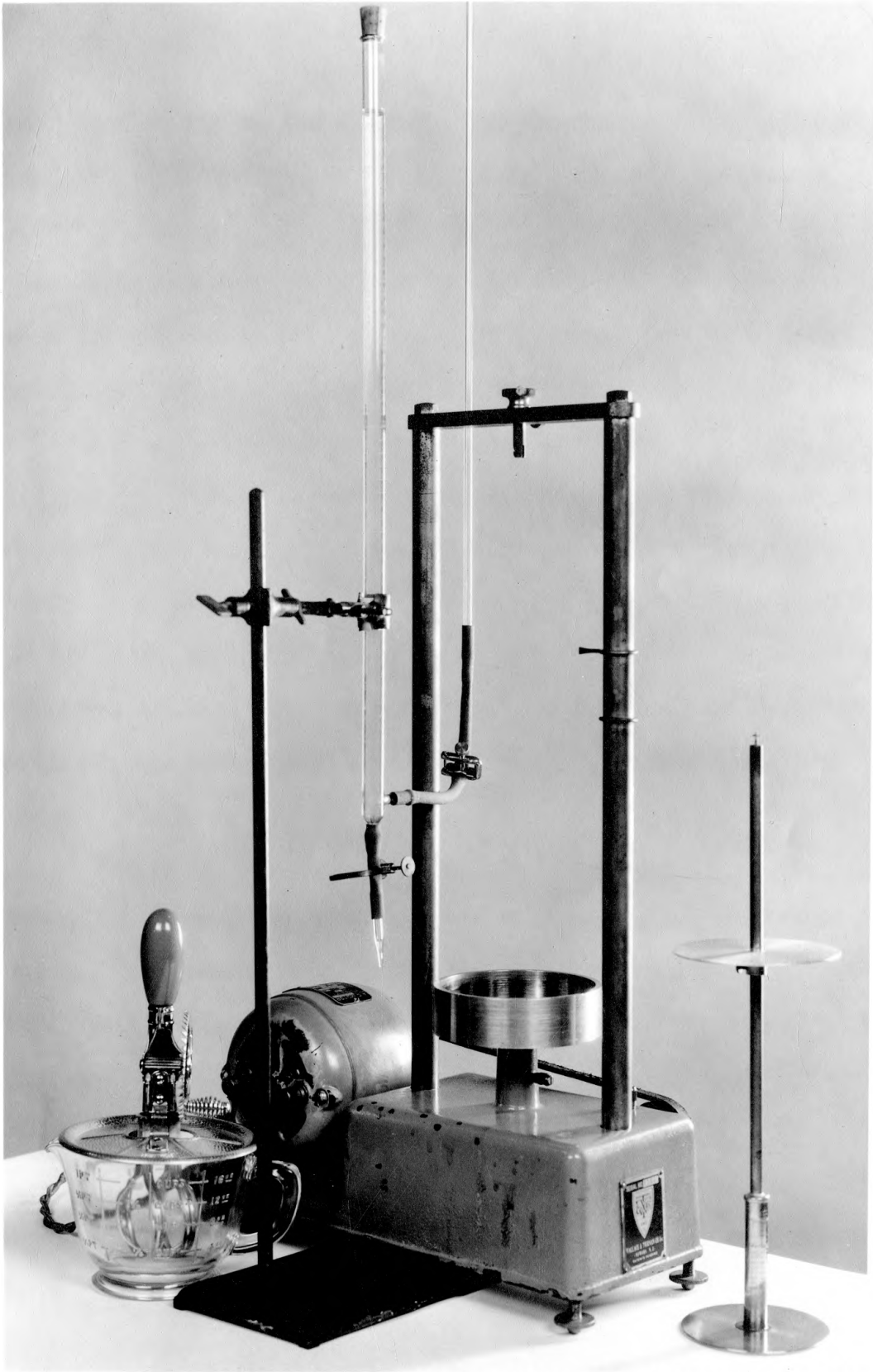


Figure 3 - Showing the viscosimeter and apparatus used in determining the viscosity titration curves.

used was equal to that amount just necessary to satisfy the flour as indicated by its absorption plus 80 cc. in excess, thus giving a total of 95 - 100 cc. of water. The viscosity determinations were carried out in a small room at a temperature of 25.5 (±1) degrees centigrade. All flours as well as a supply of distilled water were kept in this room. After measuring the water into the bowl by means of a burette, the flour was added on top of water. The contents were then put into a suspension by means of a Dover type egg beater. The wheel of the Dover was turned at the rate of two revolutions per second for exactly 3.5 minutes. The beater was rotated around the walls of the bowl during the beating to insure complete suspension of all the flour.

After the exact 3.5 minutes of beating, 3 drops of caprylic alcohol were added and the contents beat for 20 seconds to remove foam. The suspension was placed immediately into the viscosimeter cup, after which the disc was inserted at an angle to prevent the formation of air pockets beneath the disc.

After connecting the disc to the viscosimeter saddle, the cup was started rotating, the excess rotation of the disc being damped by the palm of the index finger. The

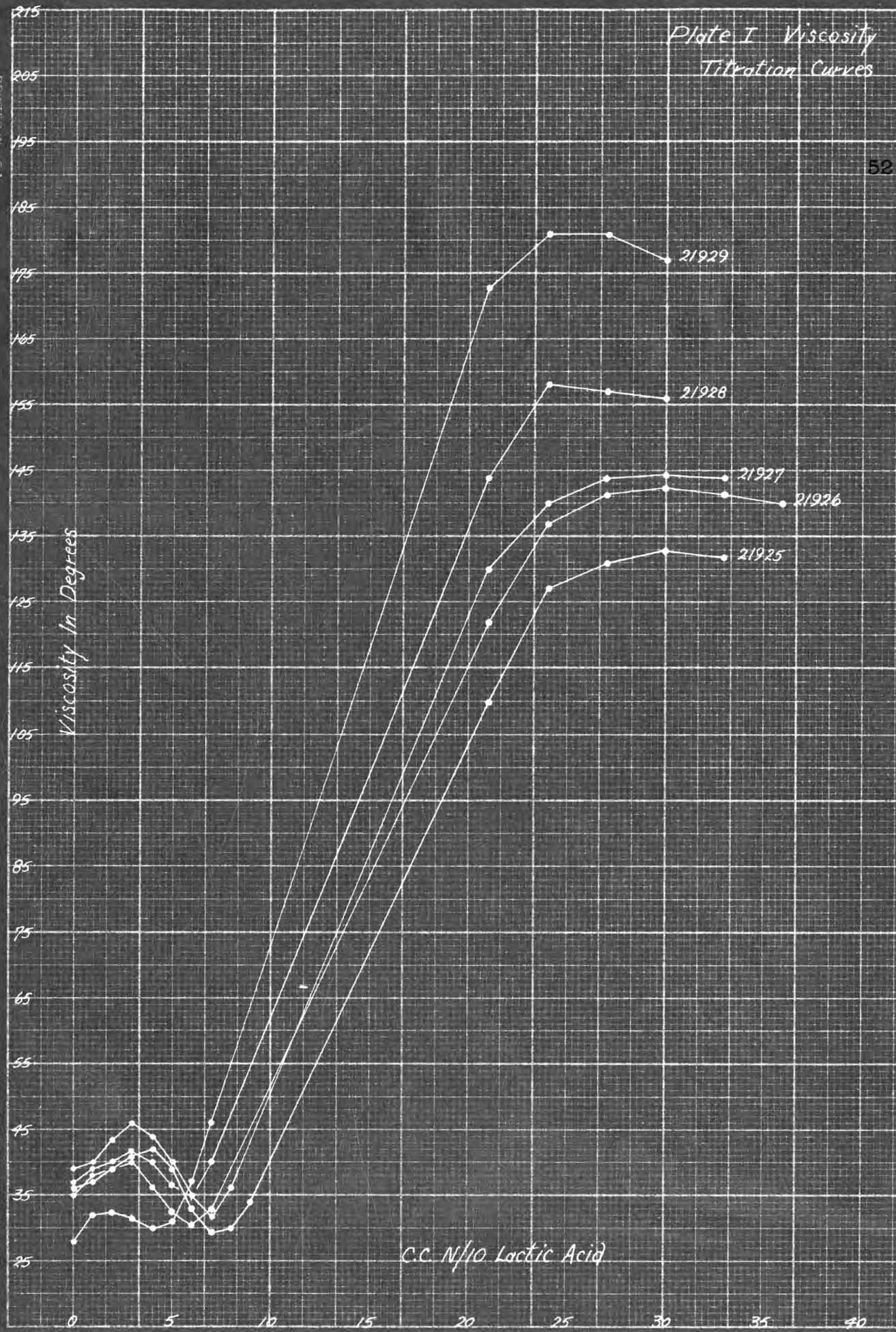
reading was taken 30 seconds after the cup was started rotating.

Then after adding 1 cc. of N/10 lactic acid from the burette while the cup was still rotating, the cup was stopped and the disc bob removed from the saddle. The acid was stirred into the mixture by taking 25 rapid strokes with the disc in an up and down manner, care being taken not to raise the disc above the top of the suspension.

The cup was again started rotating, the disc was damped, and a second reading was taken 30 seconds after the cup was started rotating. This procedure was repeated until the major viscosity peak was reached, the entire procedure requiring less than 40 minutes. After the minimum viscosity was reached, several cc. of acid were added at one time until the major peak was almost reached, after which the titration was carried out more cautiously.

The data were plotted with cubic centimeters of N/10 lactic acid as the abscissa and viscosity in degrees as the ordinate.

Plate I Viscosity Titration Curves



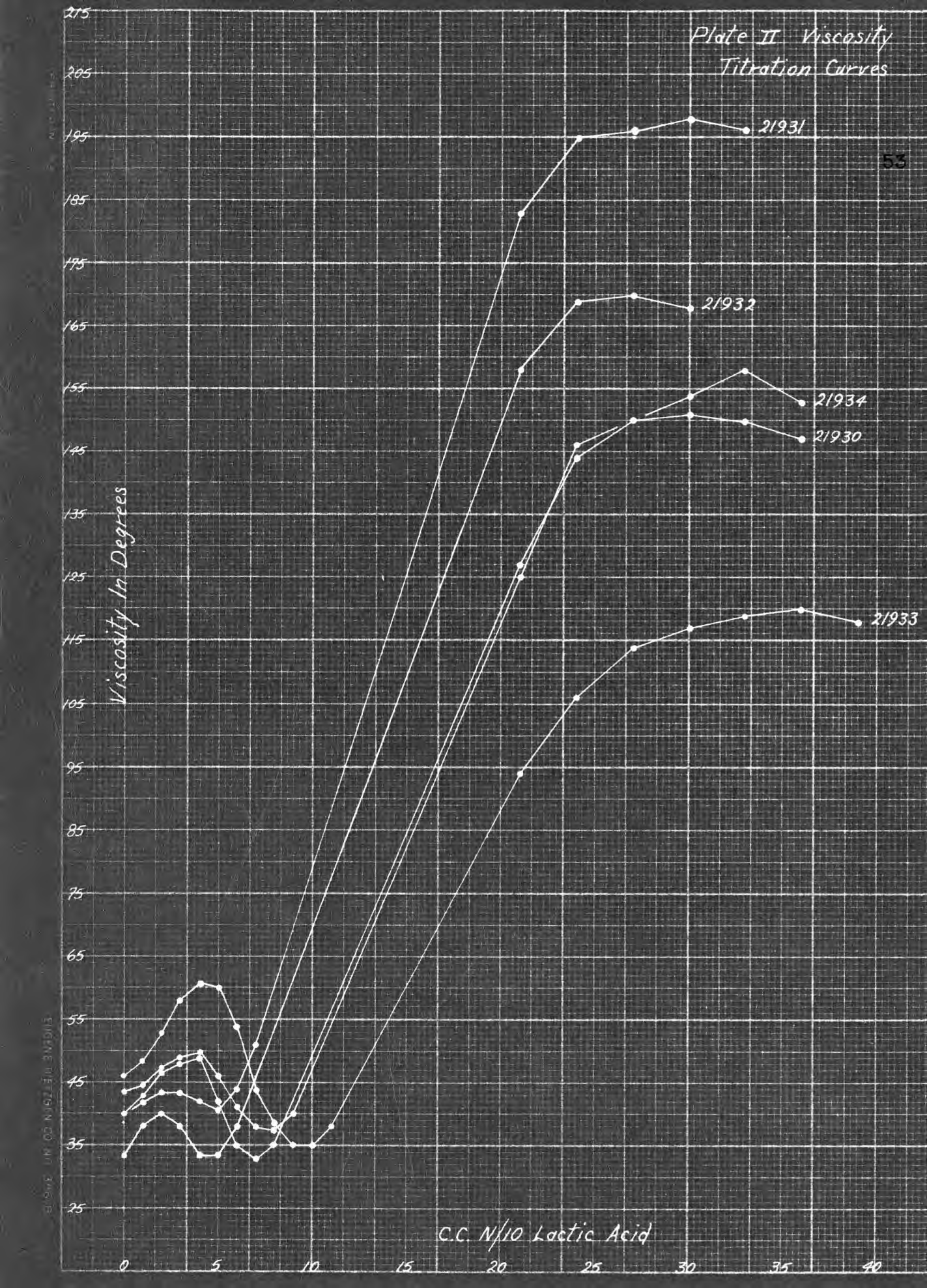


Plate II Viscosity Titration Curves
21931
21932
21934
21930
21933
Viscosity In Degrees
C.C. N/10 Lactic Acid
215
205
195
185
175
165
155
145
135
125
115
105
95
85
75
65
55
45
35
25
0
5
10
15
20
25
30
35
40

Plate III Viscosity Titration Curves

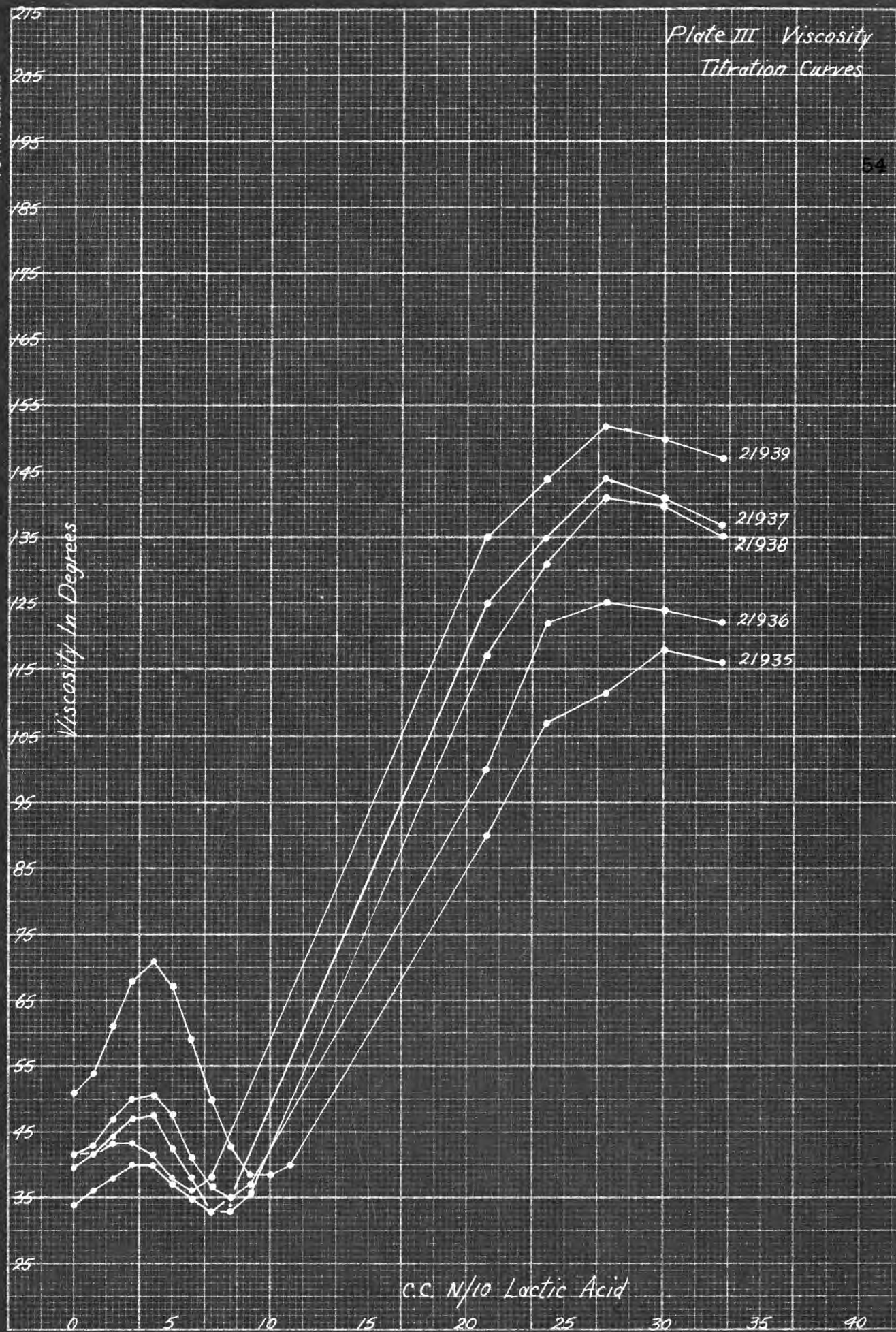


Plate IV Viscosity Titration Curves

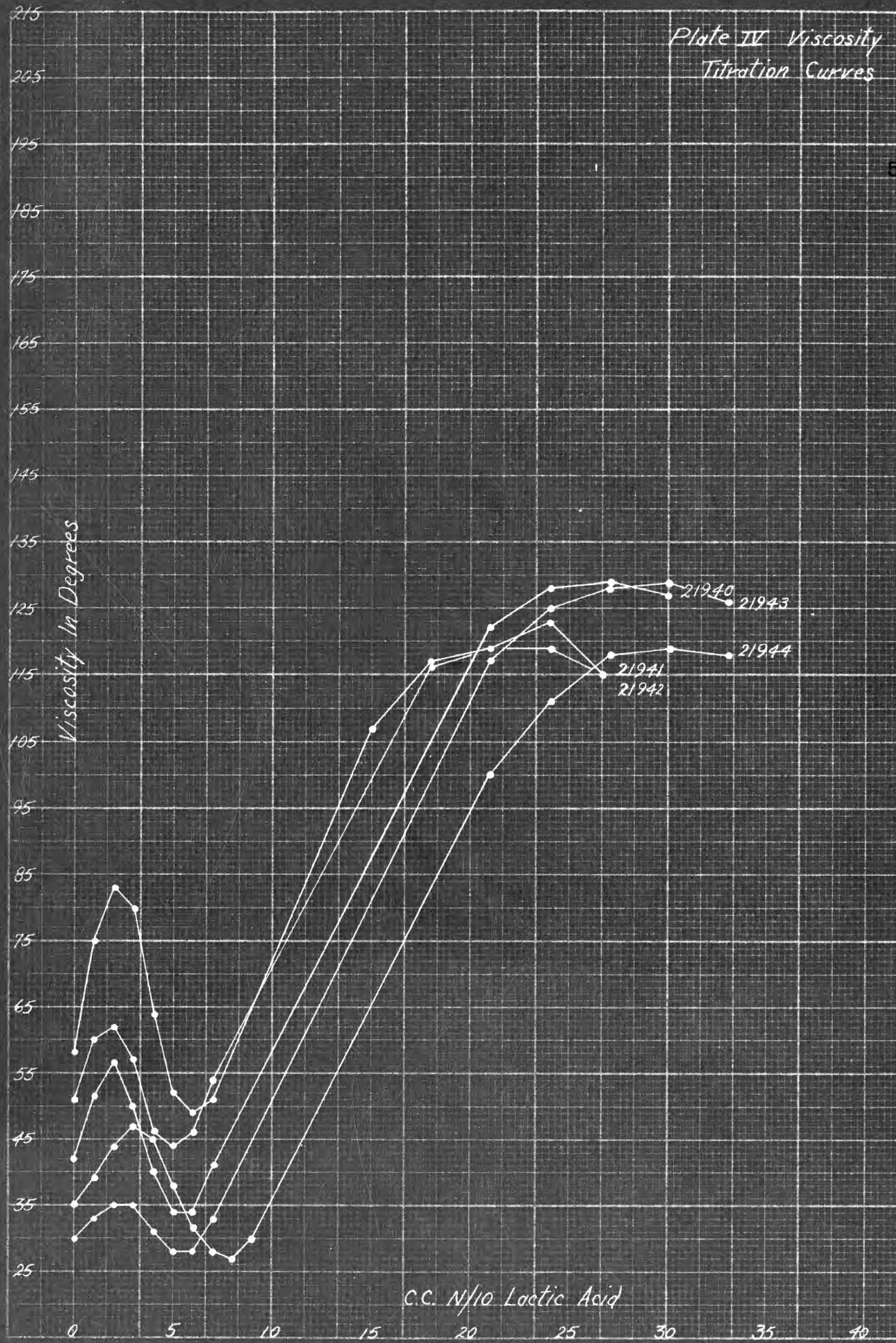


Plate V Viscosity Titration Curves

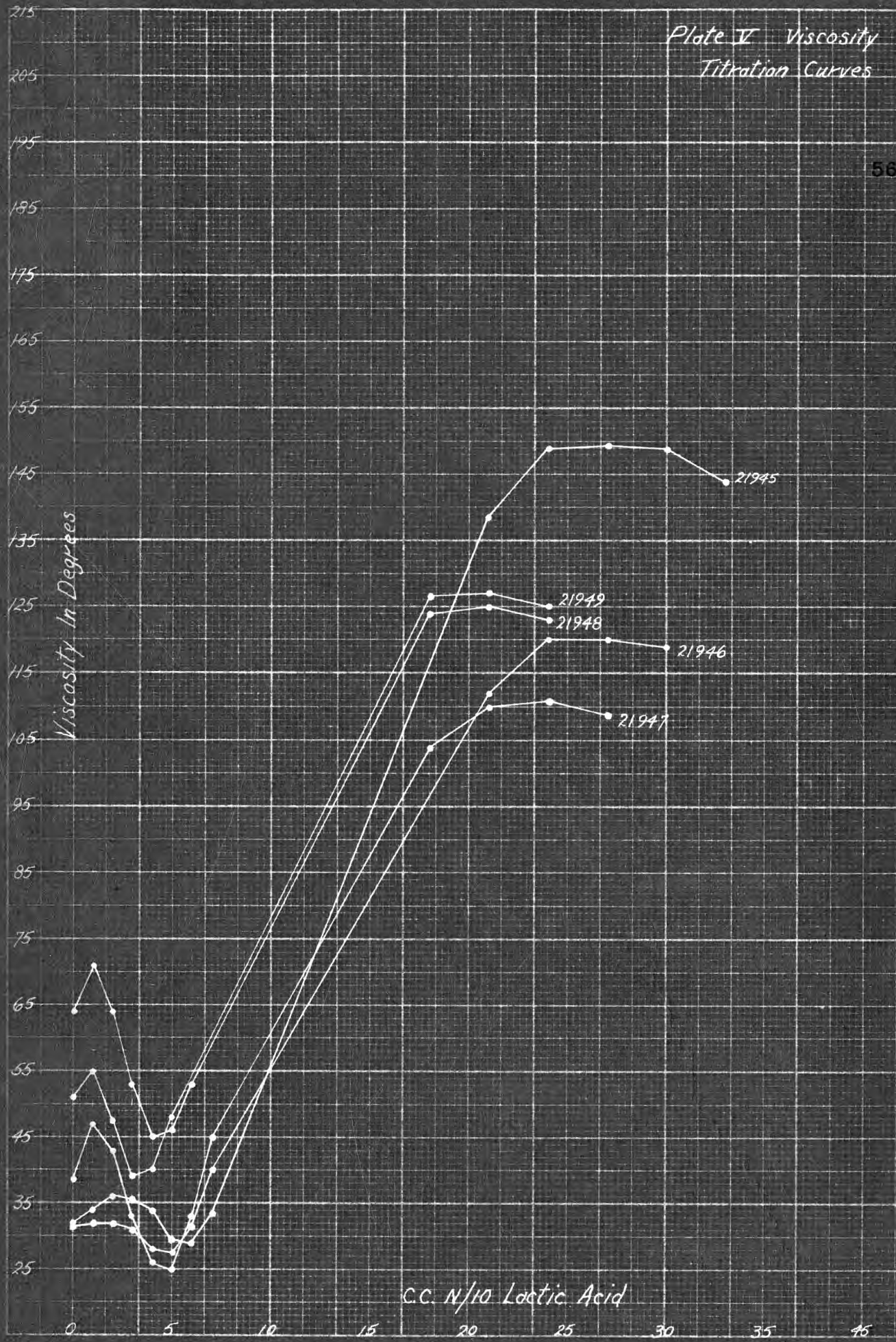
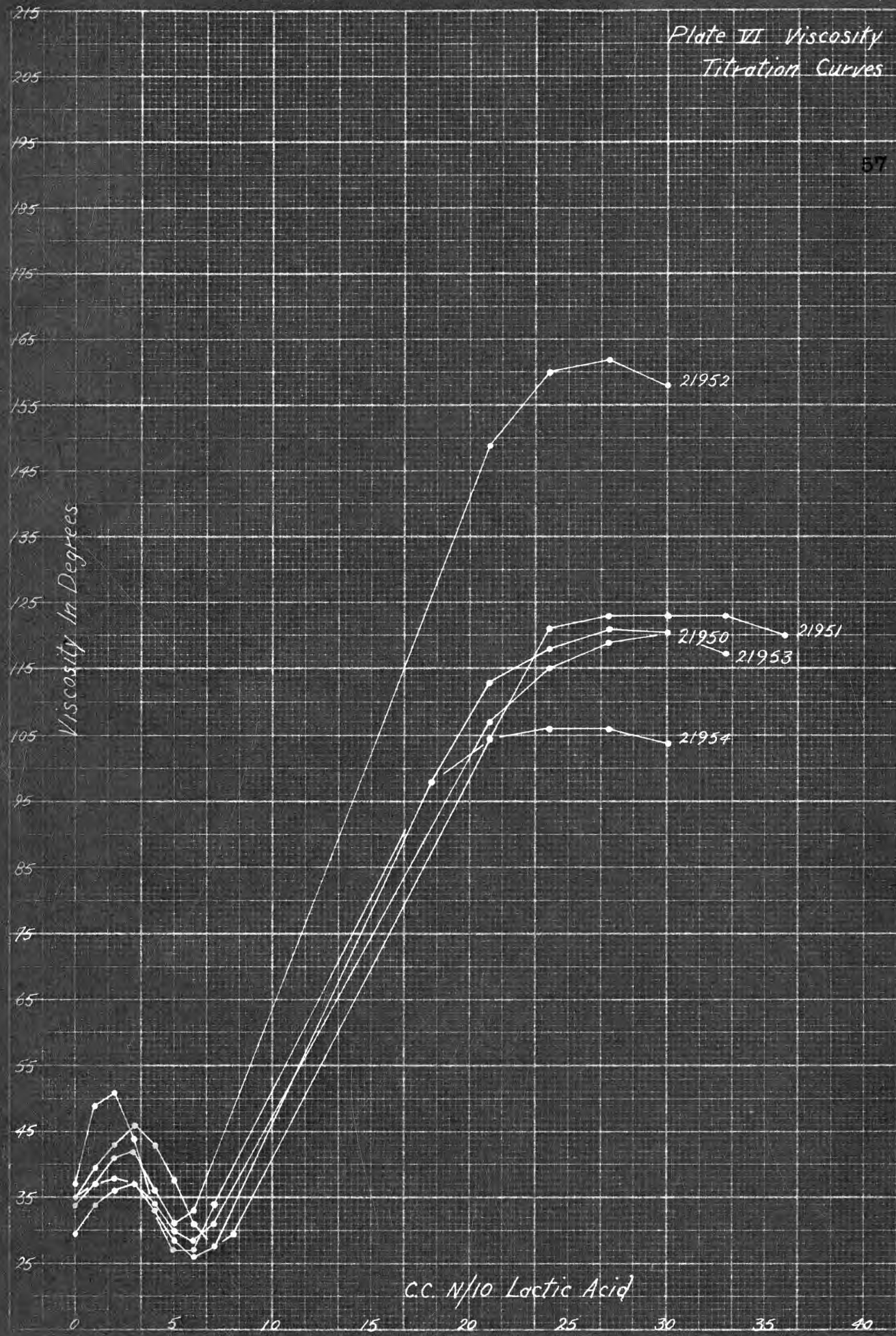


Plate VI Viscosity Titration Curves



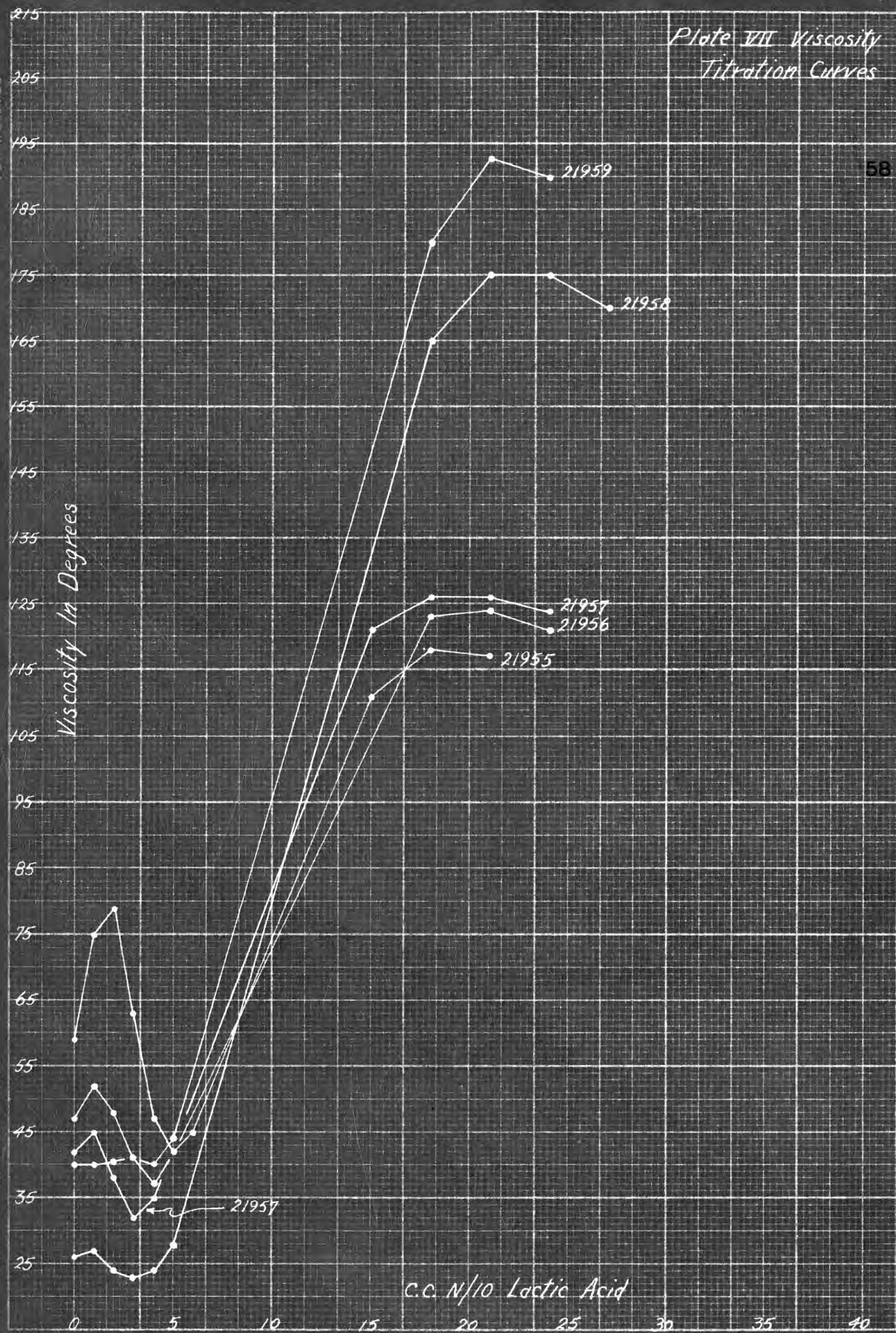


Plate VII Viscosity
Titration Curves
Viscosity in Degrees
C.C. N/10 Lactic Acid
21959
21958
21957
21956
21955
21957
215
205
195
185
175
165
155
145
135
125
115
105
95
85
75
65
55
45
35
25
0
5
10
15
20
25
30
35
40

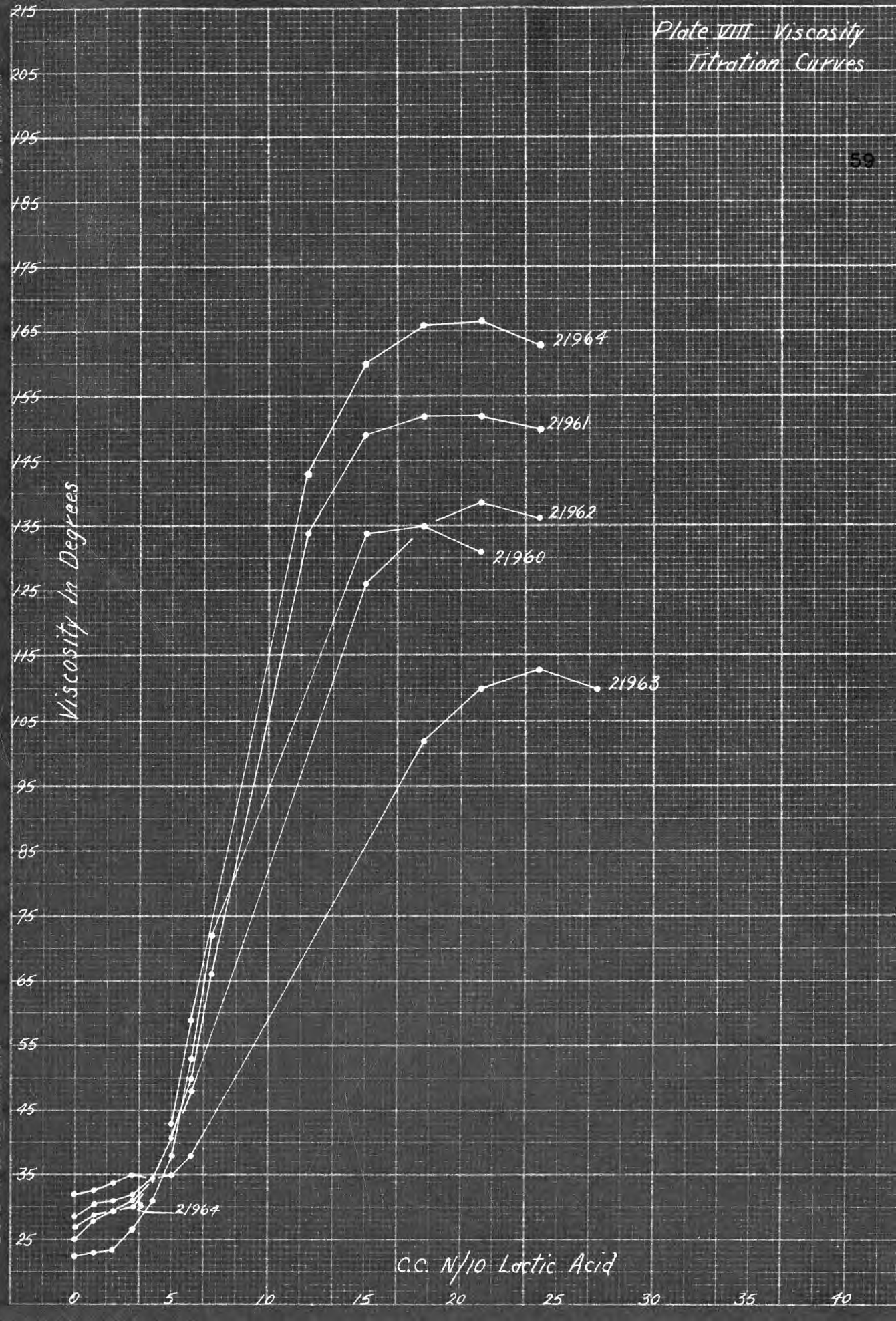


Plate VIII Viscosity Titration Curves
Viscosity in Degrees
C.C. N/10 Lactic Acid
21964
21961
21962
21960
21963
21964
215
205
195
185
175
165
155
145
135
125
115
105
95
85
75
65
55
45
35
25
0
5
10
15
20
25
30
35
40

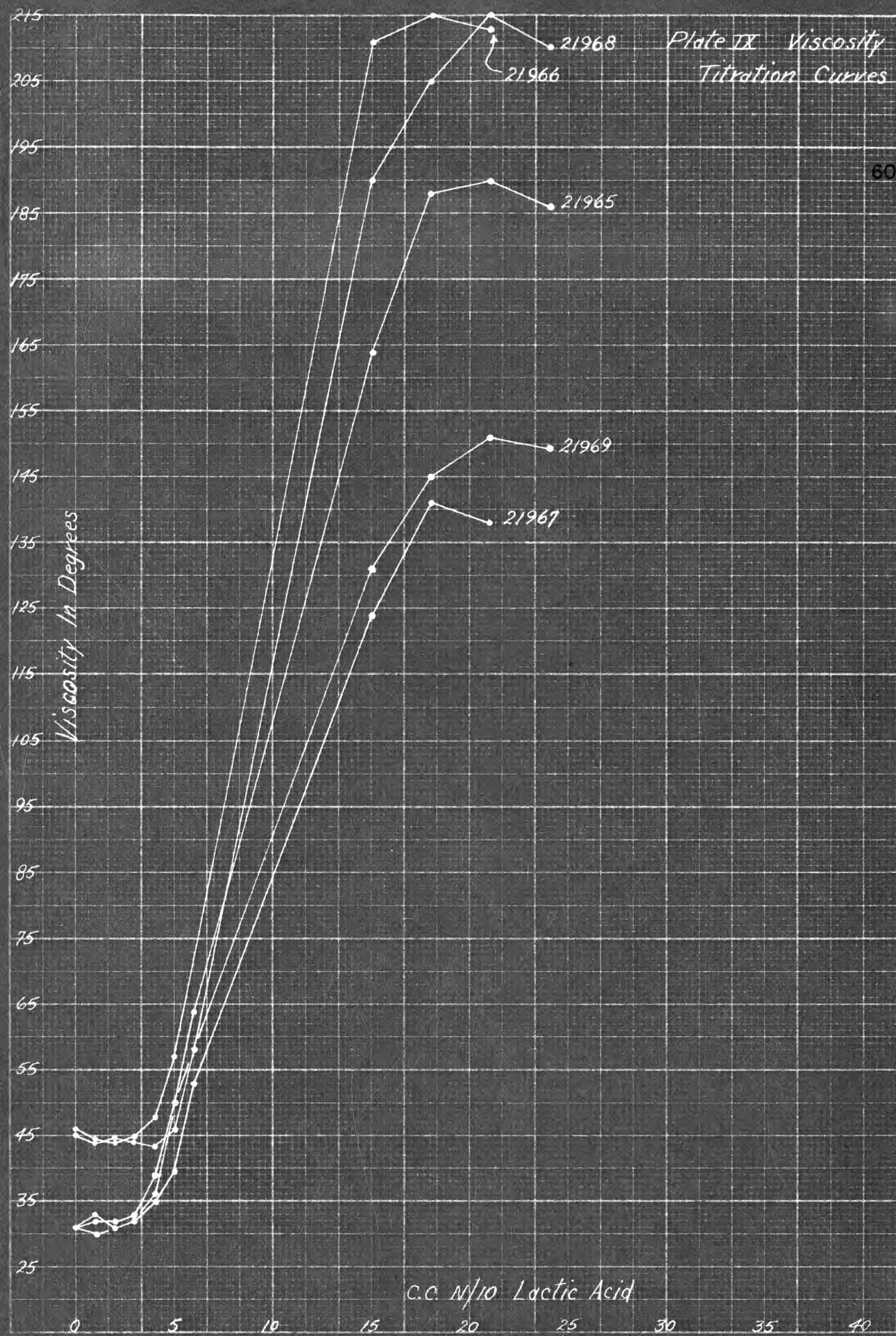


Plate IX Viscosity Titration Curves
21968
21966
21965
21969
21967
Viscosity In Degrees
215
205
195
185
175
165
155
145
135
125
115
105
95
85
75
65
55
45
35
25
C.C. N/10 Lactic Acid
0
5
10
15
20
25
30
35
40

Plate X Viscosity Titration Curves

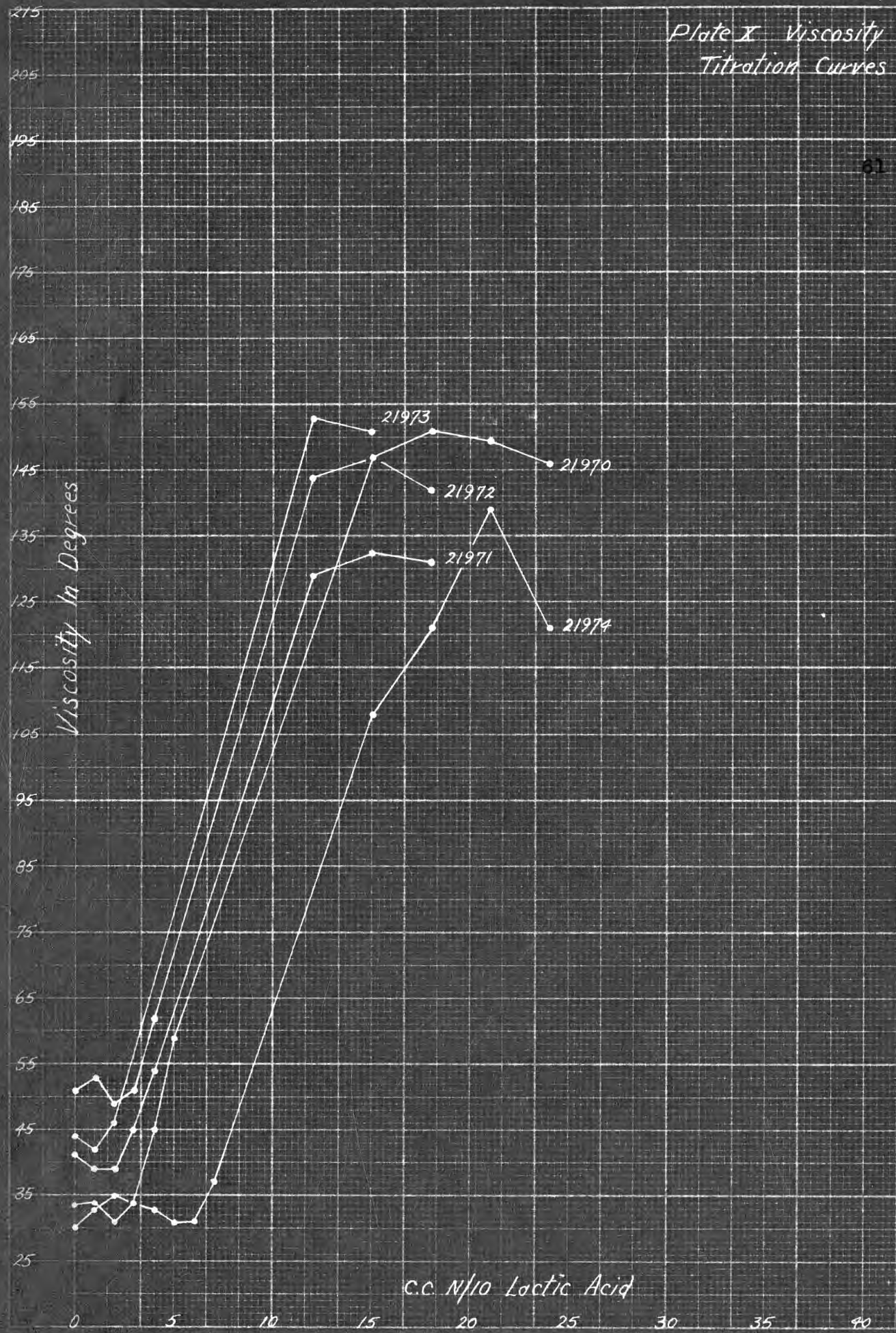


Plate XI Viscosity Titration Curves

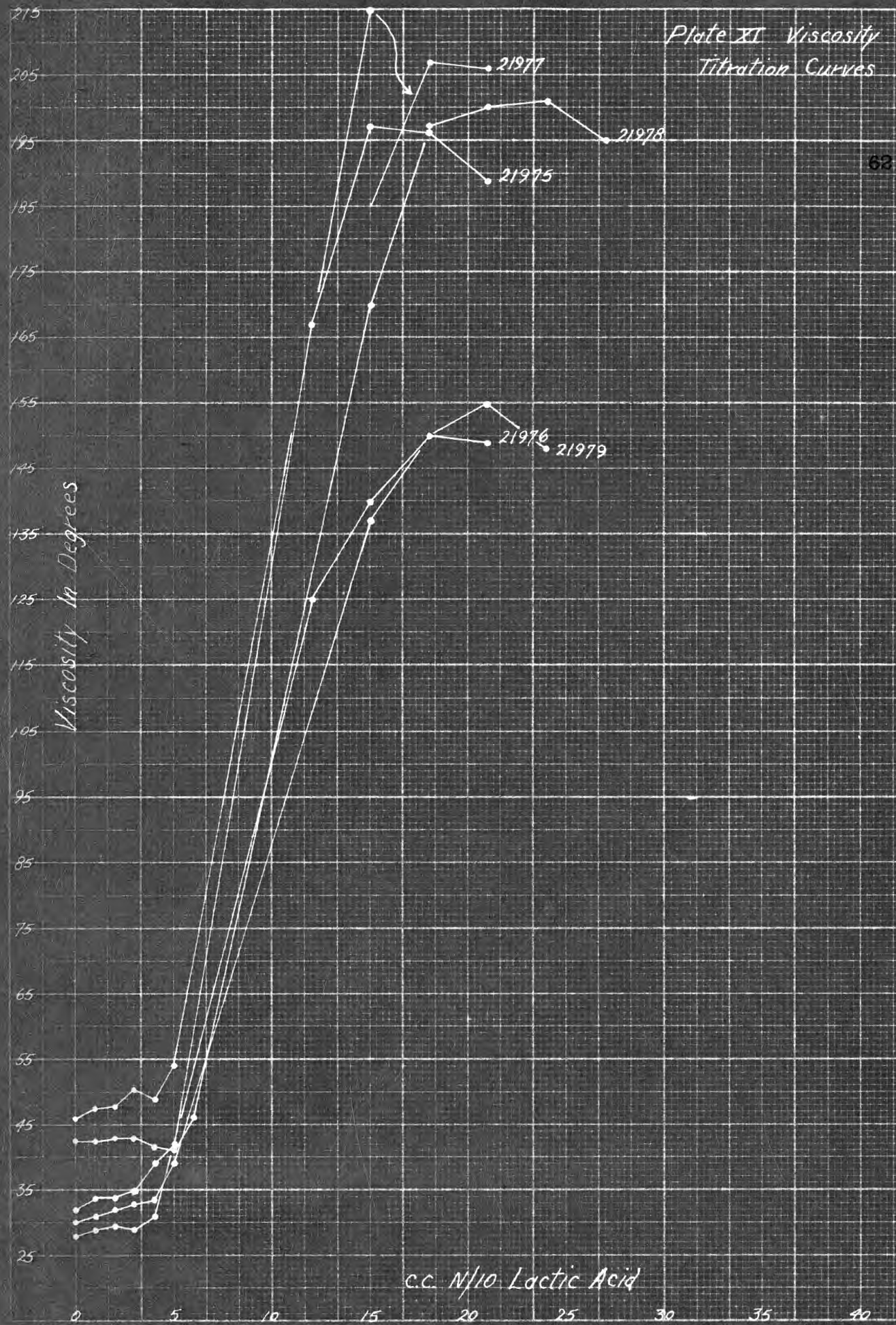


Plate XII Viscosity Titration Curves

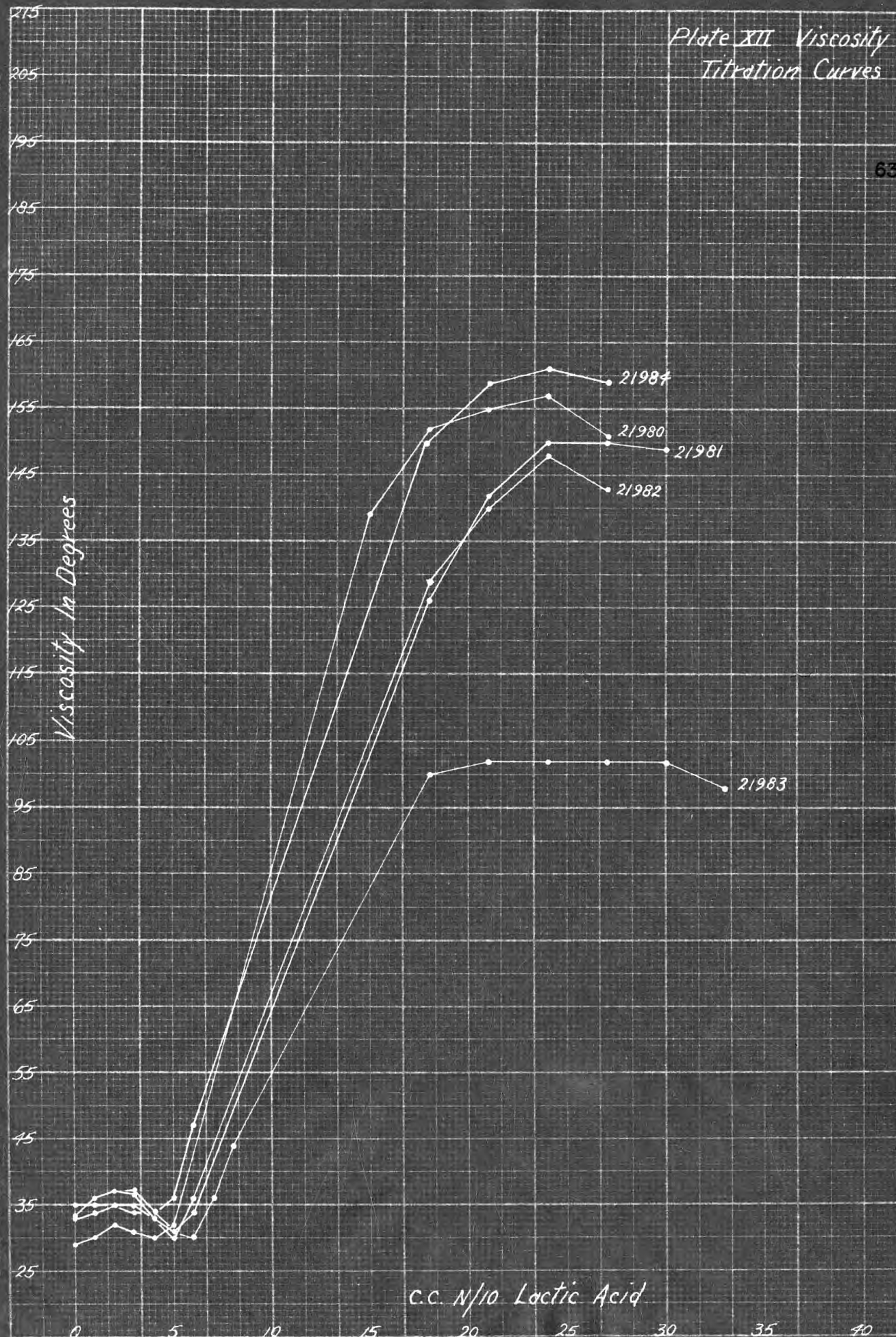


Plate XIII Viscosity Titration Curves

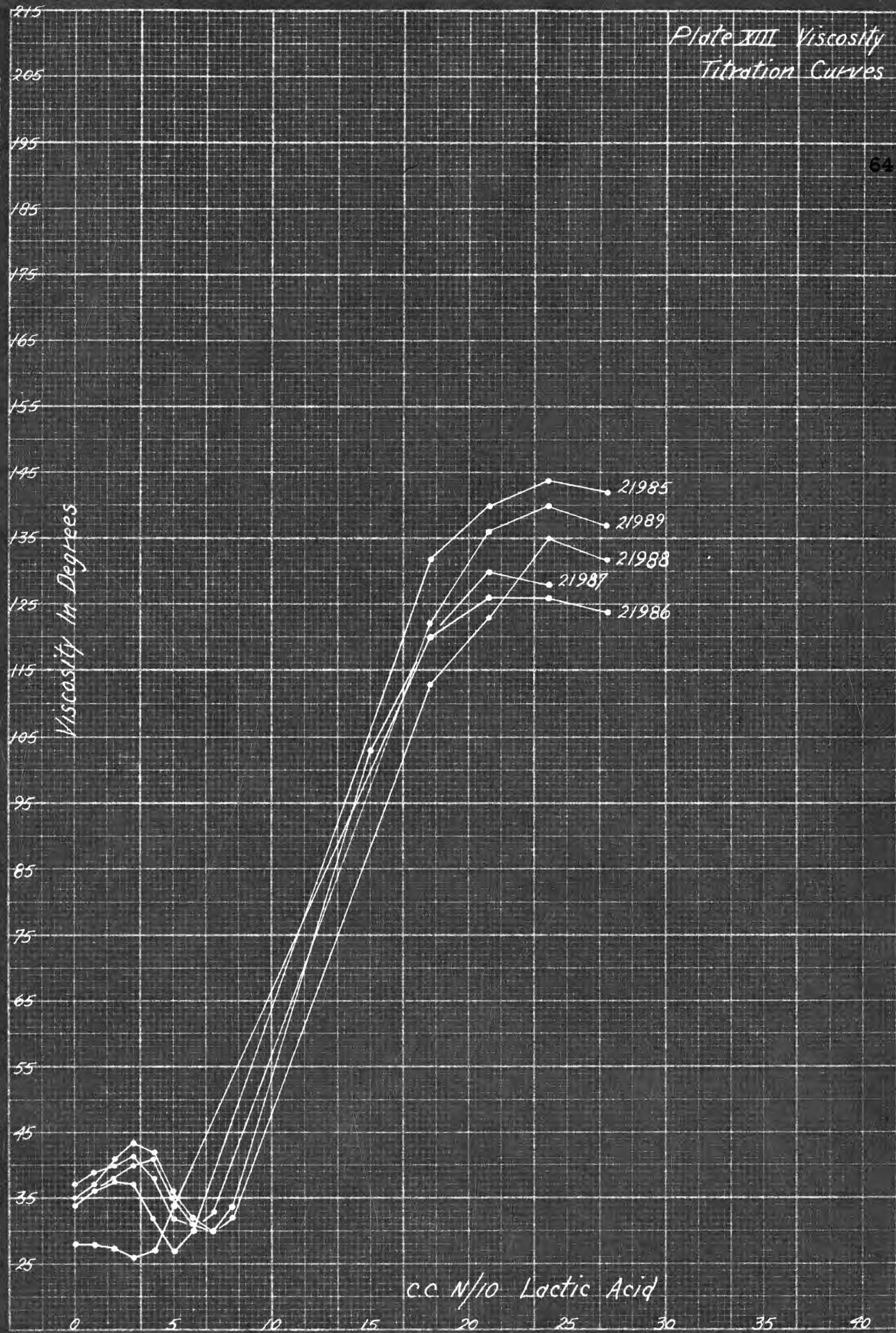


Plate XIV Viscosity Titration Curves

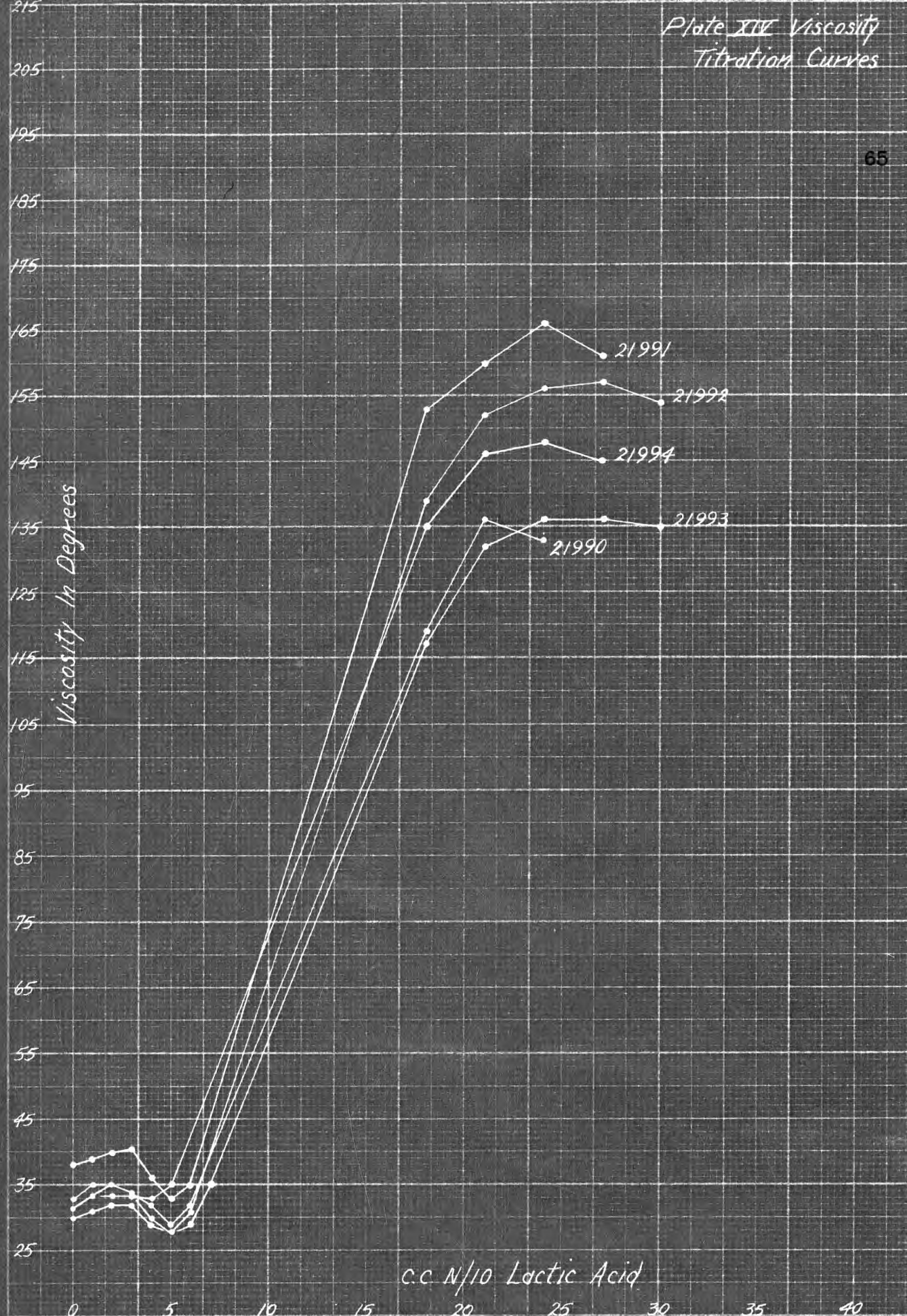


Plate XV Viscosity Titration Curves

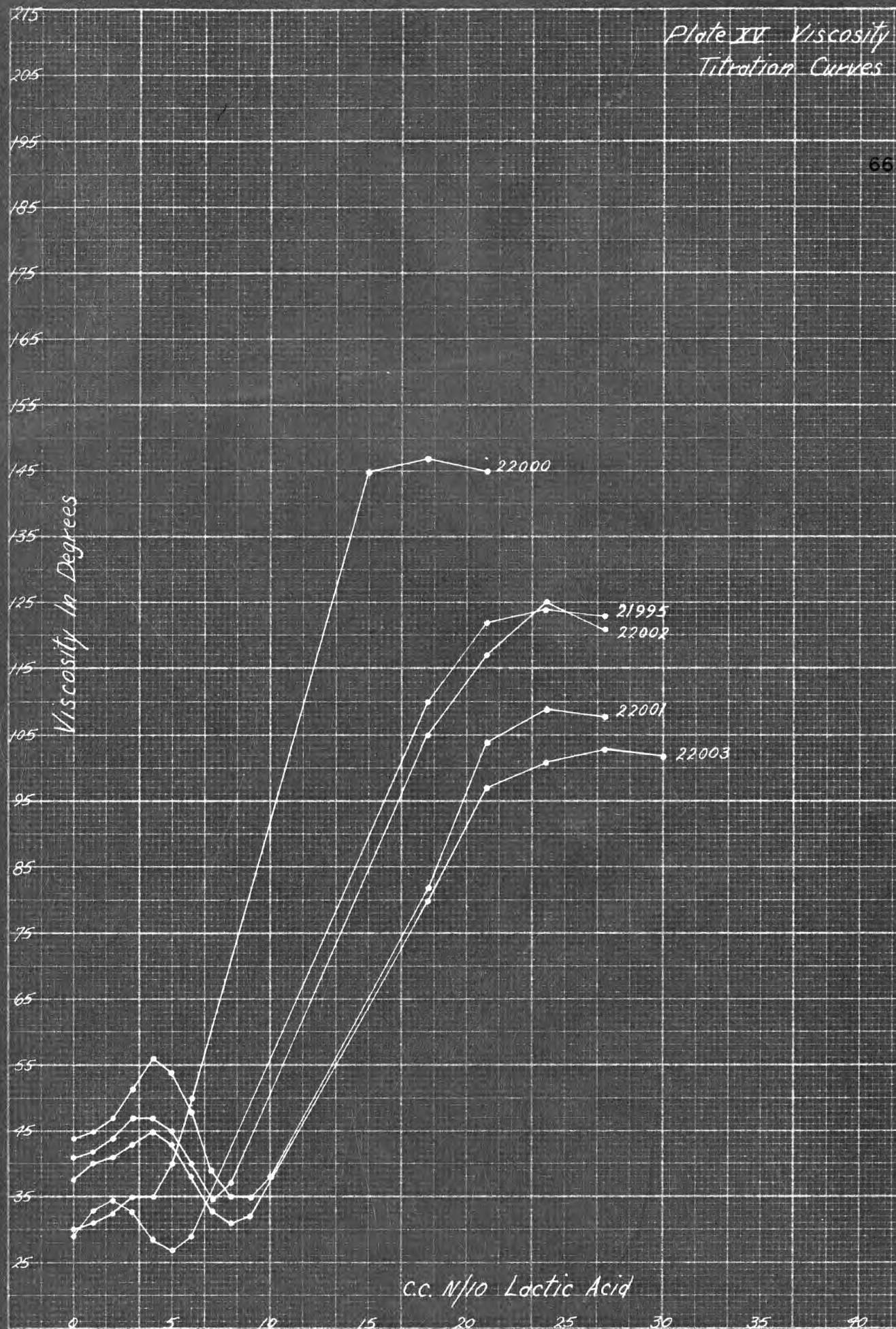
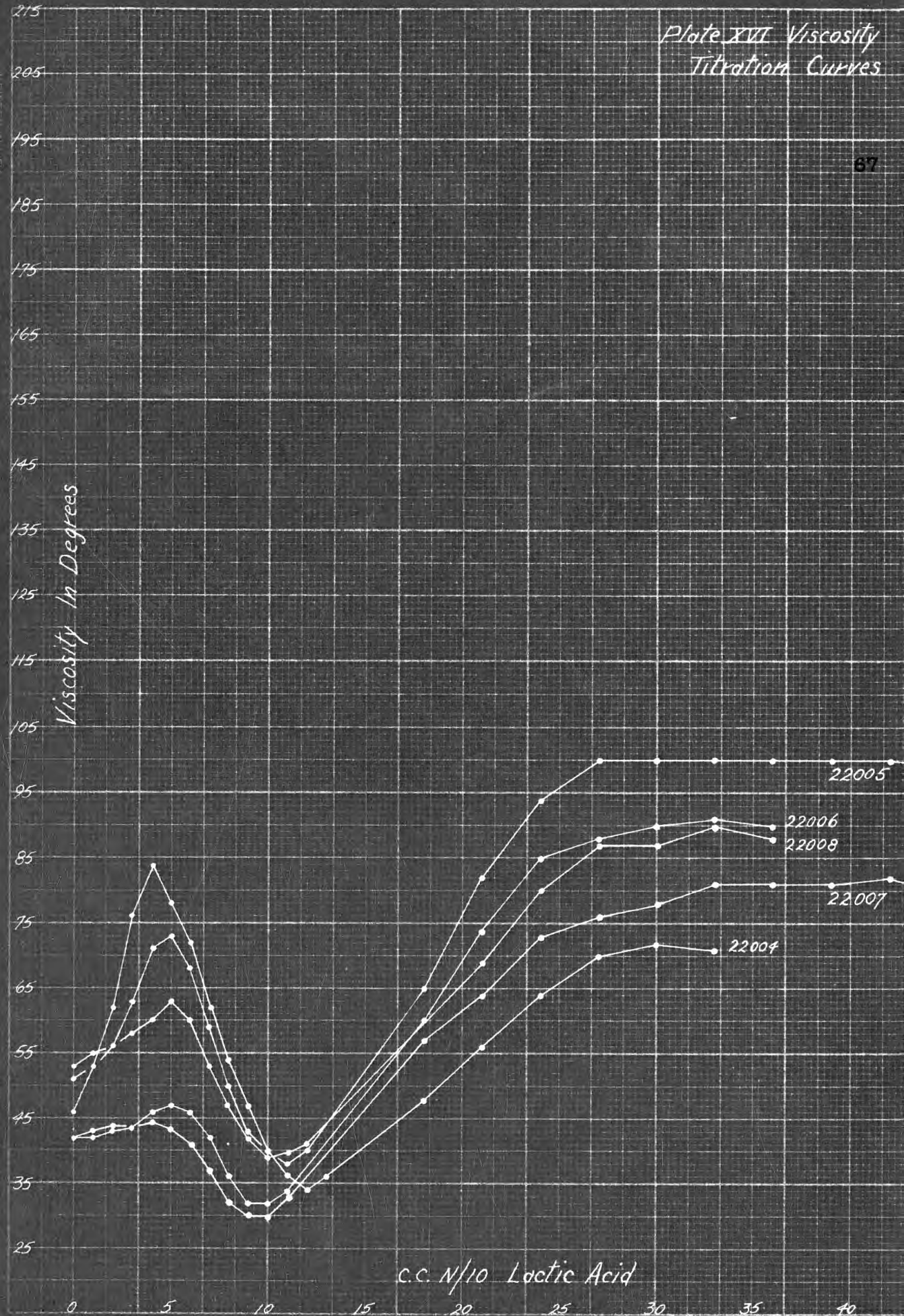


Plate XVI Viscosity Titration Curves



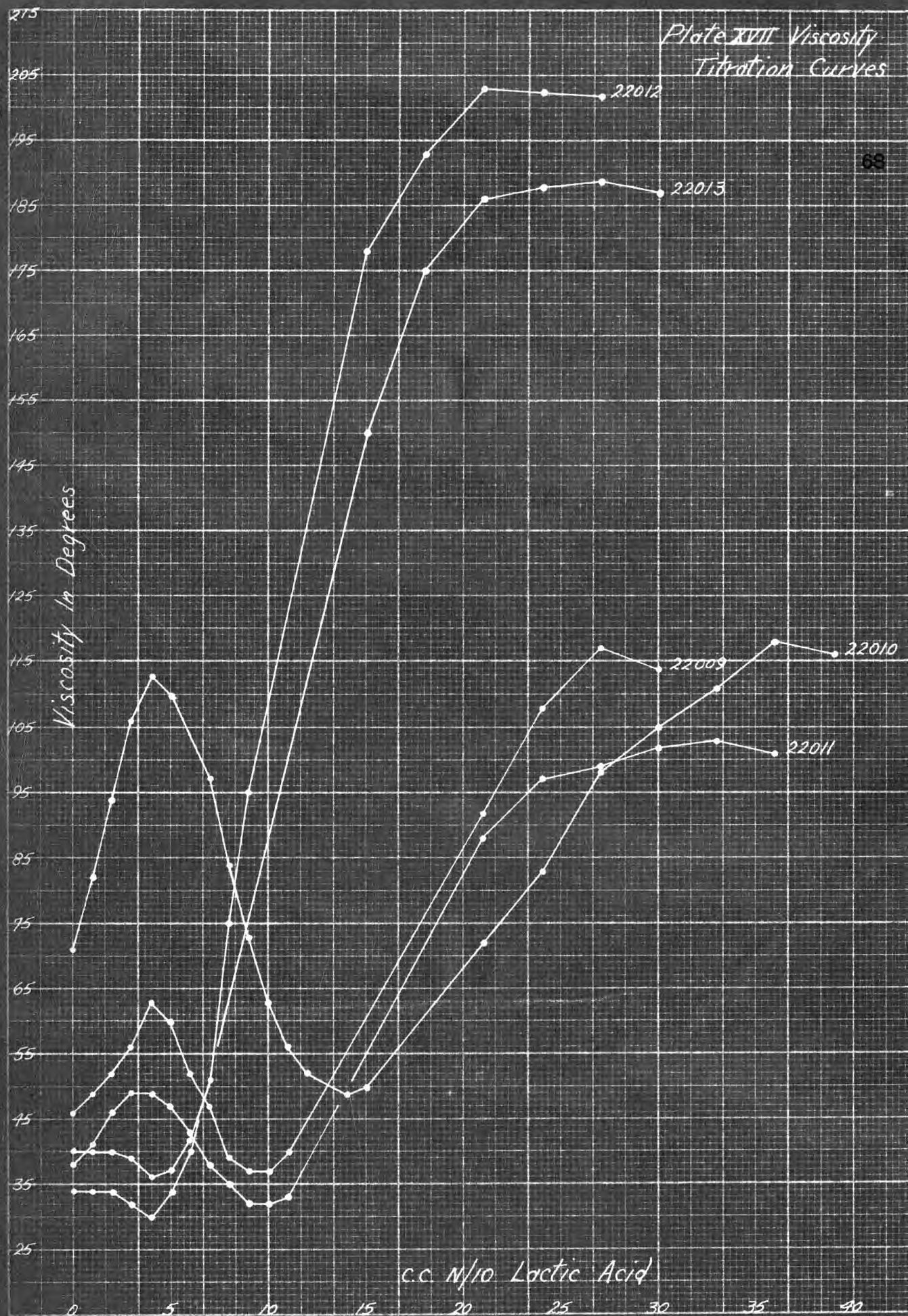


Plate XVII Viscosity Titration Curves
22012
22013
22009
22010
22011
Viscosity in Degrees
c.c. N/10 Lactic Acid
215
205
195
185
175
165
155
145
135
125
115
105
95
85
75
65
55
45
35
25
0
5
10
15
20
25
30
35
40

Plate XLIII Viscosity Titration Curves

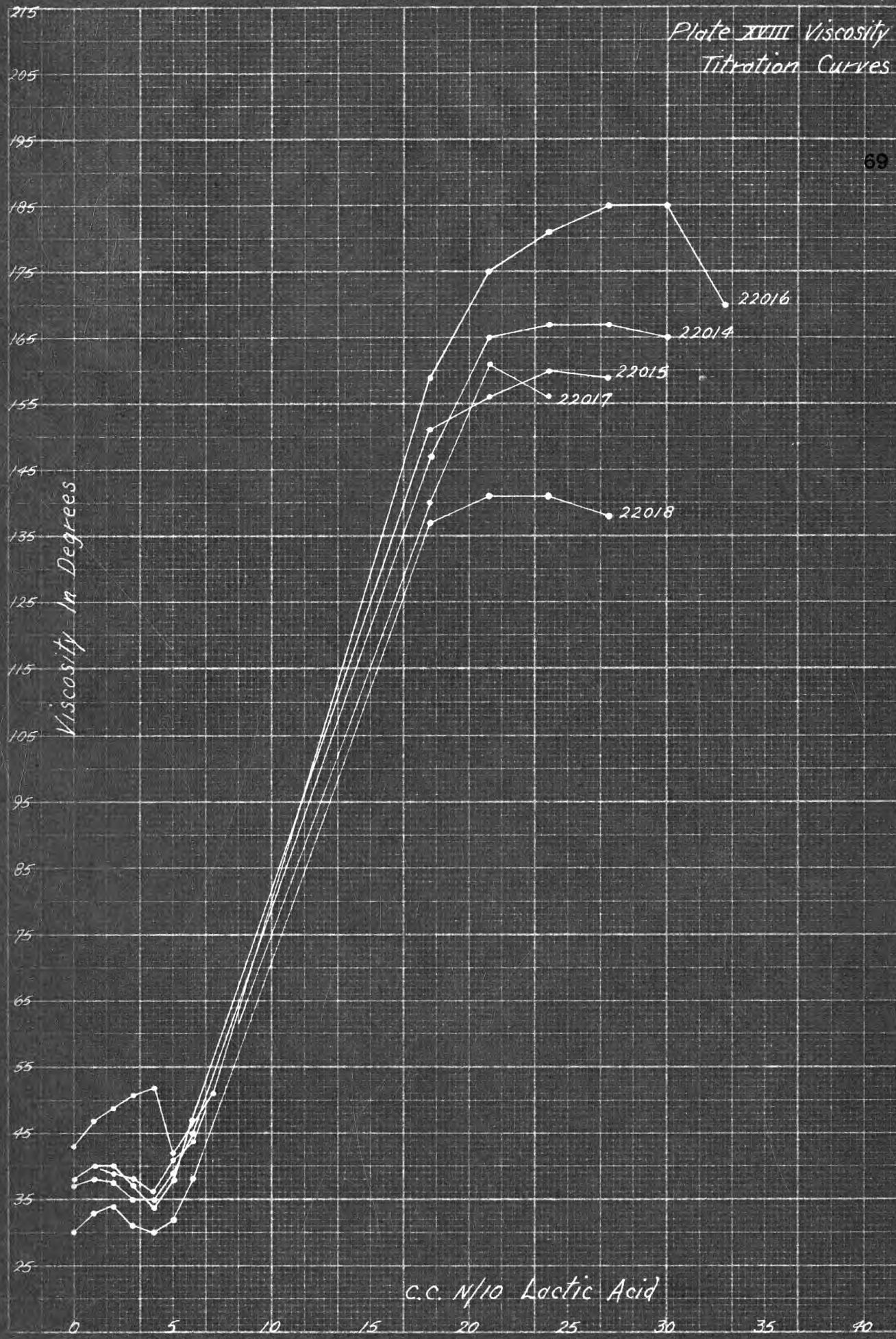


Plate XIX Viscosity Titration Curves

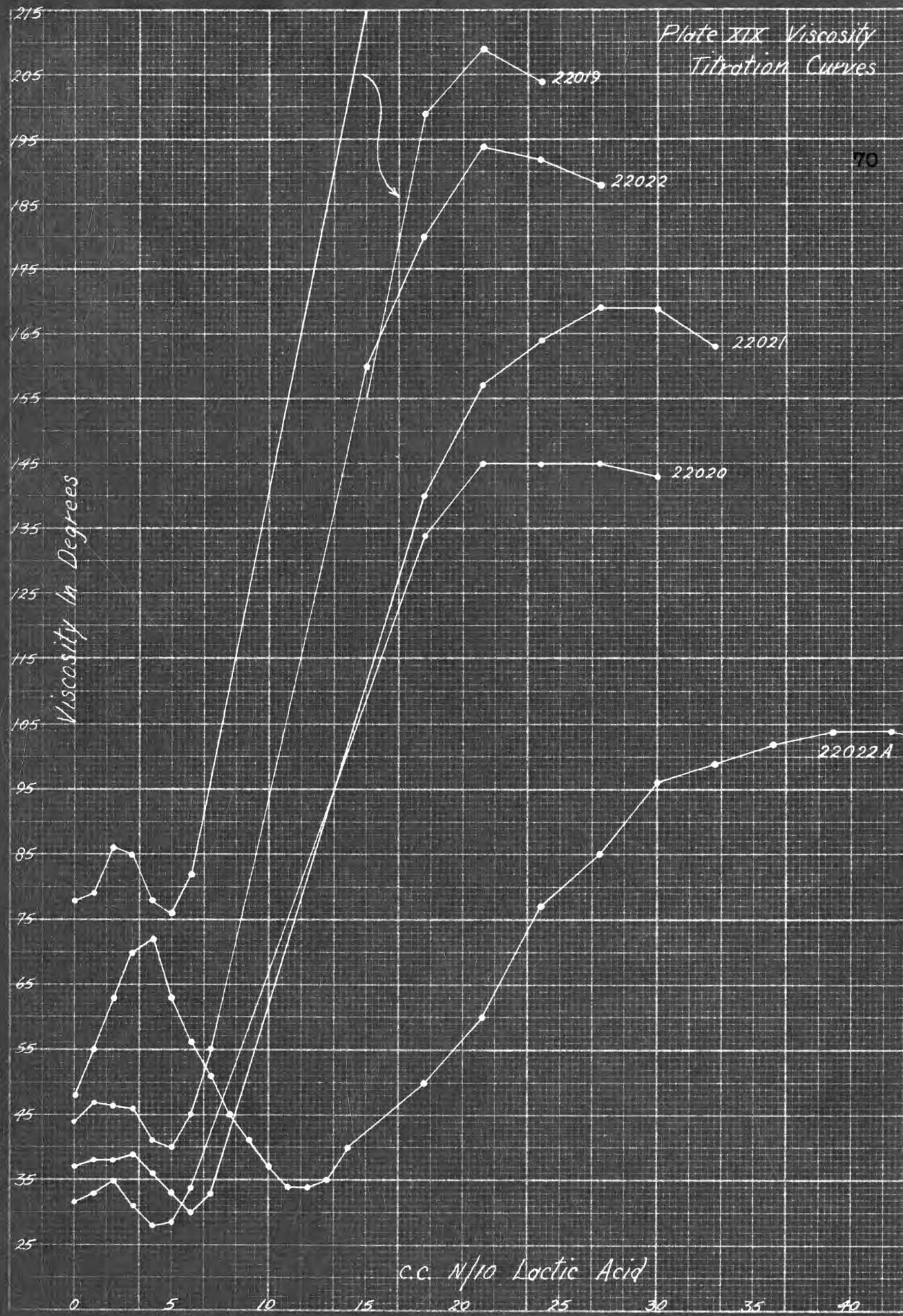


Plate XX Viscosity Titration Curves

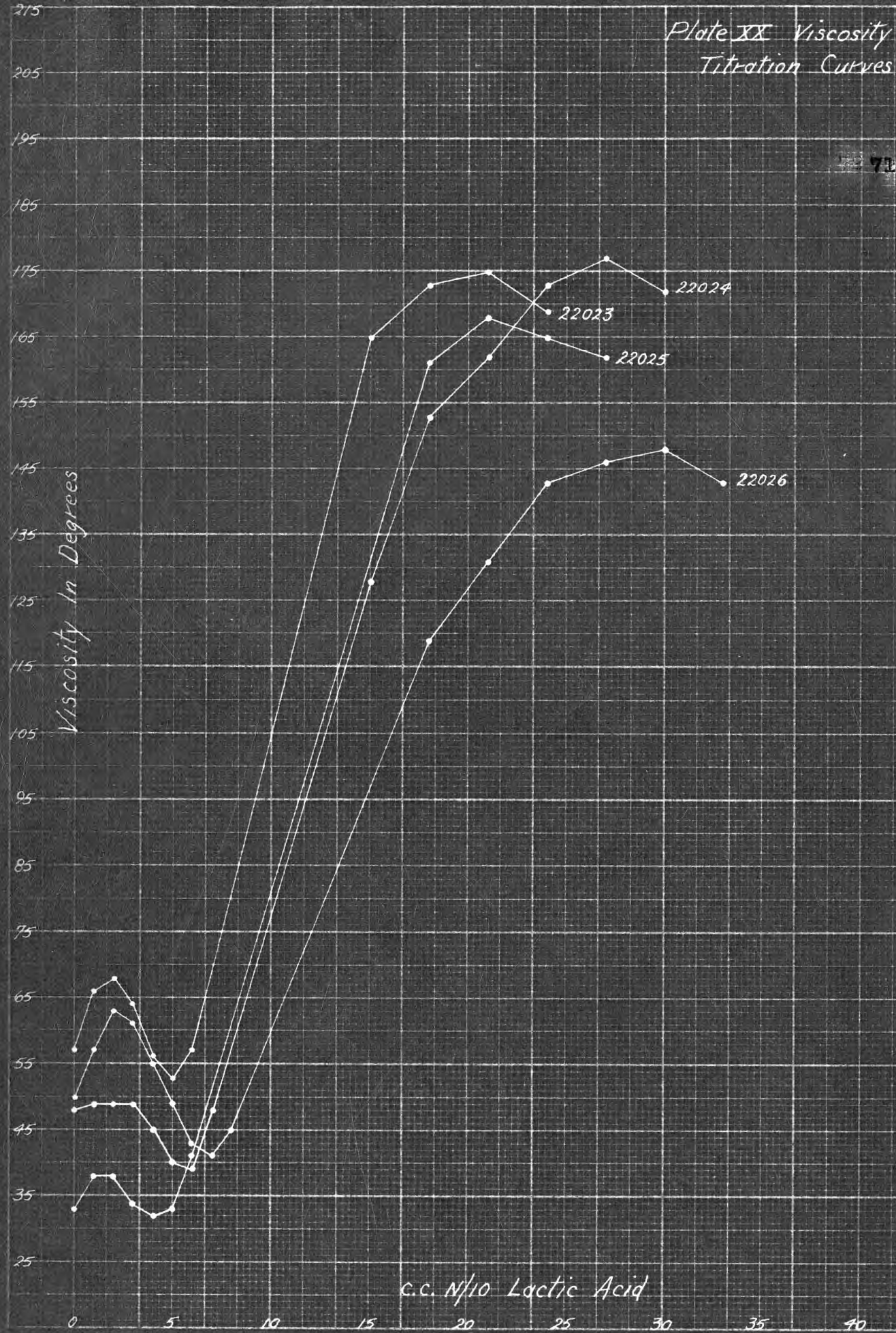


Table III Viscosity titration curves

Mill No.	Initial viscosity	Horizontal distances from initial visc. to			Vertical distances from initial visc. to		
		minor peak	minimum	major peak	minor peak	minimum	major peak
21925	36	4	7	30	6	-6.5	97
21926	35	3	6	30	5	-4.5	107.5
21927	39	3	7	30	7	-7	105.5
21928	36.5	3	6	24	5	-1.5	121.5
21929	28	2	4	27	4.5	2	153
21930	40	4	7	30	9	-7	111
21931	40	3	5	30	3.5	1	158
21932	33.5	2	5	27	6.5	0	136.5
21933	46	4	10	36	14.5	-11	74
21934	43.5	4	8	33	6	-6	114.5
21935	51	4	10	30	20	-12.5	67
21936	41.5	4	8	27	9	-6.5	83.5
21937	34	4	7	27	6	-1.5	110
21938	39.5	4	8	27	8	-6.5	101.5
21939	42	3	6	27	1.5	-6	110
21940	42	2	6	27	14.5	-8	87
21941	58	2	6	24	25	-9	65
21942	51	2	5	24	11	-7	68
21943	30	3	6	30	5	-2	99
21944	35	3	8	30	12	-8	84

Table III Continued

21945	32	2	6	27	4	-3	117.5
21946	31.5	2	5	27	0.5	-4	88.5
21947	38.5	1	5	24	8.5	-13.5	72.5
21948	64	1	4	21	7	-19	61
21949	51	1	3	21	4	-12	76
21950	29.5	3	6	27	7.5	-3.5	91.5
21951	35	3	7	33	11	-7	88
21952	34	3	5	27	8	-3	128
21953	35	2	6	30	3	-6.5	85
21954	37	2	6	27	14	-10	69
21955	59	2	5	18	20	-17	59
21956	47	1	4	21	4.5	-10	77
21957	42	1	3	21	3	-10	84
21958	26.5	1	3	24	0.5	-3.5	148.5
21959	40	3	4	21	1.5	0	153
21960	22.5			18			112.5
21961	28.5			21			123.5
21962	25			21			113.5
21963	32	3	4	24	3	2	81
21964	27			21			139.5
21965	31			21			159
21966	46		2	18		-2	169
21967	31	1	2	18	2	0	110
21968	45		4	21		-1.5	170
21969	31		1	21		-1	120
21970	33.5	1	2	18	0.5	-2.5	117.5
21971	41		2	15		-2	91.5
21972	51	1	2	15	2	-2	96
21973	44		1	12		-2	109

Table III Continued

21974	30	2	6	21	5	1	109
21975	32			15			165
21976	28	2	3	18	1.5	1	122
21977	46	3	4	18	4.5	3	191
21978	42.5	3	5	24	0.5	-1.5	158.5
21979	30			21			125
21980	29	2	4	24	3	1	128
21981	33.5	2	5	27	3.5	-2.5	116.5
21982	33	3	5	24	2	-3	115
21983	33	3	6	30	3.5	-3	69
21984	35		4	24		-1	126
21985	34	2	5	24	3.5	-7	110
21986	28		3	24		-2	98
21987	34.5	3	7	21	9	-4.5	95.5
21988	34.5	4	7	24	6.5	-4.5	100.5
21989	37	3	6	24	4.5	-6	103
21990	31.5	2	5	21	3.5	-2.5	104.5
21991	38	3	5	24	2.5	-5	128
21992	32.5	2	5	27	2.5	-4.5	124.5
21993	30	3	5	27	2	-2	106
21994	30.5	3	4	24	3	2.5	117.5
21995	29	2	5	24	5.5	-2	95
22000	30			18			117
22001	44	4	9	24	12	-9	65
22002	41	4	7	24	6	-6	84
22003	37.5	4	8	27	7.5	-6.5	65.5
22004	46	4	12	30	38	-12	26
22005	51	5	11	42	22	-13	49
22006	42	5	10	33	5	-10	49
22007	42	4	10	42	2.5	-12	40

Table III Continued

22008	53	5	10	33	10	-14	37
22009	46	4	10	27	17	-9	71
22010	71	4	14	36	42	-22	47
22011	38	4	10	33	11	-6	65
22012	40		4	21		-4	163
22013	34		4	27		-4	155
22014	37	1	4	27	1	-2	130
22015	38	2	4	24	2	-4	122
22016	43	4	5	30	8.5	-1	142
22017	38	1	4	21	2	-2	123
22018	30	2	4	24	4	0	111
22019	78	2	5	21	8	-2	191
22020	31.5	2	4	27	3.5	-3.5	113.5
22021	37	3	6	30	2	-7	132
22022	44	1	5	21	3	-4	150
22023	57	2	5	21	11	-4	118
22024	48	3	6	27	1	-9	129
22025	33	2	4	21	5	-1	135
22026	50	2	7	30	13	-9	98
22022A	48	4	12	42	24	-14	56

DISCUSSION OF RESULTS

Chemical and Physical Analysis of Flours

Absorption. From an examination of the maltose and absorption values given in Table I, it is evident that a definite correlation exists. The value of the coefficient of correlation was 0.912. This result is significant in view of the fact that the maltose values varied from 56 to 320 mg. of maltose per 10 gm. of flour. This is suggestive evidence that the condition of the starch plays an important role when determining the absorption by the super centrifuge. During the baking of the different flours, many low absorption doughs were noted as being far below the absorption which the original flours seemed to require. Many other high absorption doughs were so slack that it was almost necessary to scoop them as a means of handling throughout the baking process. These false absorptions alone are enough to prevent a correlation between the viscosity and baking values of the different flours.

Maltose. The maltose value of flour has been studied by numerous investigators, and the data in the literature serve to establish the importance of this property of flour in relation to baking strength.

The maltose values of the flours used in this investigation varied from 56 to 320 mg. of maltose per 10 gm. of flour. Considering this fact it is most probable that the flours were not baked under conditions that would permit each to display its value as a bread flour. After correlating the maltose value with the gas production value of each flour, a correlation coefficient of 0.939 was found to exist. Since the gas production was determined using only flour, water, and yeast, the correlation can not be used as a definite indication that every flour with a low maltose value will have a low gas production when baked. There were undoubtedly low malt value flours which, nevertheless, produced sufficient gas during the bake as a result of the sugar added at the dough stage. One would expect to produce good bread from some of these low-malt-value flours which otherwise gave indications of good quality.

In future work of this nature, this factor could be largely overcome by bringing each flour up to a minimum maltose value by adding the required amount of germinated wheat to supplement the deficiency of enzymes.

Gas Production and Gas Retention. According to the work of Sherwood and Bailey (1926) the baking strength of flour milled from wheat low in diastatic activity was increased

when 3 per cent of sprouted kernels was added to the wheat. The increased strength was measured in terms of a decidedly increased gas production, an increase in gas retention, increased loaf volume, and superior grain and texture. Time for proofing or raising the doughs in the pan was reduced, color of crumb appeared whiter, and the crust of the loaves was browner and more pleasing in appearance when the mixture contained germinated wheat.

One of the chief requirements of a flour of good quality is its ability to produce large, well-piled loaves. There are many bread flours which produce large loaves as a result of a high gas production and retention, but the resulting loaves do not have a desirable grain and texture. They are, therefore, not flours of good quality.

It is, however, most important that flours being tested for quality have a reasonably high gas production and retention. Baking results indicated that if a loaf is to be properly developed with respect to grain and texture, it is so developed as a result of a good gas production. If the physico-chemical condition of the protein, as well as the gas producing capacity of the flour, is desirable, there will result a large loaf possessing good external and internal characteristics. If, on the other hand, the flour has a low gas production it will be physically and

chemically improperly developed and at the same time will have an inferior loaf volume.

It seems that it would be advisable to treat each flour to the extent that it would possess, at least, a certain minimum gas production capacity. The physico-chemical properties of the flour could then be studied.

Viscosity Titration Curves

As stated in the problem, the object of this investigation was to determine the value of viscosity as a measure of flour quality in different wheat varieties. Viscosity in this work, as applied in the titration curves (Plates 1 to 20), shows large differences not only between flours from different wheat varieties but also between flours from the same variety of wheat.

When the initial viscosity, minor peak, minimum, and maximum viscosity values of each flour were compared with the respective viscosity values of other flours, large differences were evident in many cases. There was hope that these viscosity values at definite points on each curve might throw some light on quality in different flours.

The individual viscosity values (Table III) as well as different combinations of these values for each flour were studied for a possible correlation with the baking values (Table II) of the respective flours. No correlation,

however, was obtained. Even if a definite correlation should exist between these viscosity curves and the respective baking values, it is evident from the preceding discussion that a correlation could rarely be expected.

By placing all flours on a more or less equal basis chemically, the value of viscosity as an indication of the physico-chemical condition of the flour can more nearly be determined after a comparison with the quality of the flours as indicated by the baking test.

It seems evident from this investigation that the viscosity test does not indicate the value of certain important chemical properties of flour such as the maltose value and the gas production capacity of flour. These chemical factors should be more or less standardized in order that the physico-chemical differences of flours as indicated by the baking test might be more comparable to the physico-chemical properties of flour as determined by viscosity measurements.

SUMMARY AND CONCLUSIONS

A definite correlation existed between the maltose and absorption values as determined by the super centrifuge. The value of the coefficient of correlation was 0.912.

This result is significant in view of the fact that the maltose values varied from 56 to 320 mg. of maltose per 10 gm. of flour. This is suggestive evidence that the condition of the starch plays an important role when determining the absorption by the super centrifuge. The flours with extremely low or extremely high absorptions were undoubtedly harmed or prevented from responding to the baking procedure as they normally would.

After correlating the maltose value with the gas production value of each flour, a correlation coefficient of 0.939 was found to exist.

Since the gas production was determined using only flour, water, and yeast, the correlation can not be used as a definite indication that every flour with a low maltose value had a low gas production when baked. The reason for this is because sugar was added at the dough stage.

In future work of this nature, this factor could be largely overcome by bringing each flour up to a minimum maltose value by adding the required amount of germinated wheat to supplement the deficiency of enzymes.

Baking results indicated that if a loaf is to be properly developed with respect to grain and texture, it is

so developed as a result of a good gas production, providing the physico-chemical condition of the protein is desirable. In many previous investigations by numerous authors, the loaf volume was used as one of the most important factors in determining the quality of a flour. A flour, however, will not produce a good volume loaf if it does not possess a good gas production in the dough stage.

Viscosity titration curves presented large differences not only between flours from different wheat varieties but also between flours from the same variety of wheat.

When the initial viscosity, minor peak, minimum, and maximum viscosity values of each flour were compared with the respective viscosity values of other flours, large differences were evident in many cases.

These individual viscosity values as well as different combinations of these values for each flour were studied for a possible correlation with the baking values of the respective flours. No correlation, however, was obtained. Even if a definite correlation should exist between these viscosity curves and the respective baking values, it is evident from the chemical data on each flour that a correlation could rarely be expected.

It seems evident from this investigation that the viscosity test does not indicate the value of certain important chemical properties of flour such as the maltose value and the gas production capacity of flour. These chemical factors should be more or less standardized in order that the physico-chemical differences of flours as indicated by the baking test might be more comparable to the physico-chemical properties of flour as determined by viscosity measurements.

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